**Sustainable bio-economy that delivers the environment-food-energy-water nexus objectives: the current status in Malaysia**

W. A. Wan Ab Karim Ghani[a]*, M. A. M. Salleh[a], S. N. Adam[a], H. Z Mohd Shafri[b], S. N. Shaharum[b], K. L. Lim[c], N. J. Rubinsin[c], H. L. Lam[d], Azhan Hasan[e], S. M. C. Samsatli[f], J. F. Tapia[f], R. Khezri[a], Ida Fahani Md Jaye[a], E. Martinez-Hernandez[g]

[a] Department of Chemical & Environmental Engineering/ Sustainable Process Engineering Research Centre (SPERC), Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor
[b] Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor
[c] Fuel Cell Institute, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[d] The University of Nottingham Malaysia Campus, Dep. Chemical & Environmental Engineering, Jalan Broga, Semenyih, 43500 Selangor, Malaysia
[e] Department of Management and Humanities, Centre for Sustainable Resources, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 32610 Seri Iskandar Perak, Malaysia
[f] Department of Chemical Engineering, University of Bath, Claverton Down, BA2 7AY, United Kingdom
[g] Instituto Mexicano del Petróleo, Mexico City 07750, Mexico

*Corresponding Author; Email: wanazlina@upm.edu.my, Tel: +603-97696287

**Abstract**

Biomass is a promising resource in Malaysia for energy, fuels, and high value-added products. However, regards to biomass value chains, the numerous restrictions and challenges related to the economic and environmental features must be considered. The major concerns regarding the enlargement of biomass plantation is that it requires large amounts of land and environmental resources such as water and soil that arises the danger of creating severe damages to the ecosystem (e.g. deforestation, water pollution, soil depletion etc.). Regarded concerns can be diminished when all aspects associated with palm biomass conversion and utilization linked with environment, food, energy and water (EFEW) nexus to meet the standard requirement and to consider the potential impact on the nexus as a whole. Therefore, it is crucial to understand the detail interactions between all the components in the nexus once intended to look for the best solution to exploit the great potential of biomass. This paper offers an overview regarding the present potential biomass availability for energy production, technology readiness, feasibility study on the techno-economic analyses of the biomass utilization and the impact of this nexus on value chains. The agro-biomass resources potential and land suitability for different crops has been overviewed using satellite imageries and the outcomes of the nexus interactions should be incorporated in developmental policies on biomass. The paper finally discussed an insight of digitization of the agriculture industry as future strategy to modernize agriculture in Malaysia. Hence, this paper provides holistic overview of biomass competitiveness for sustainable bio-economy in Malaysia.

Keywords: Biomass; Biomass value chains; food-energy-water (FEW) nexus; biomass supply chains; optimization

## 1.0 Introduction

Energy demand in Malaysia has increased rapidly for few years and it is expected to reach almost 100 Mtoe (million tonnes of oil equivalent) in 2030. Statistically, the electricity generation sector in Malaysia is still highly dominated by fossil fuel. However, the electricity generation from natural gas is predicted to reduce by 13% in 2030, a reduction from 63% in 2005. The annual consumption of coal is reported at 88000 tons and 15219 tons in 1980 to 2009, respectively. With limited local coal resources, in 2030, approx. 37% of the electricity is generated from coal which have led to significant imports from Indonesia and Australia [1], [2]. It is inevitable to explore new alternative fuel resource urgently to ensure the reliability and the security of energy supply for future energy demand. Despite being blessed with conventional energy resources (i.e. oil and gas), issues regarding the fossil fuel economics fluctuations, resources depletion and environmental concerns have drove the government and societies to reduce the over reliance on these energy resources especially in electricity generation sectors and sought for more sustainable electricity supply system. This also has become the global agenda under the Sustainable Development Goals initiated by the United Nations to ensure universal access to affordable, clean and sustainable modern energy system [3]. Numerous studies have been conducted to explore the potential to generate electricity from an alternative resource and has acknowledged renewable resources; which include biomass, biogas, solar photovoltaic (PV), wind and geothermal as the suitable resources to creating more sustainable and resilience energy system.

Particularly in a tropic country like Malaysia, biomass and solar PV have been reported to have the highest potential to generate clean and sustainable electricity, as summarized in Table 1 [4]. The cumulative RE installation capacity in Malaysia is estimated to be at 11.5 GW in 2050, 34% of the power mix [5]. Futhermore, Ahmad and Tahar (2014) estimate that biomass includes the forestry and agricultural residues, and municipal solid waste holds 80% of the total renewable energy (RE) generation potential with the gross annual cumulative economic value of US$ 3,951 million in 2013 [4], [6], [7].

Table 1: Energy capacity of renewable energy resources in Malaysia

| Renewable Resources | Energy capacity (MW) | Annual power generation (MWh) | Ratio of total (%) |
|---|---|---|---|
| Biogas | 111.69 | 13366.42 | 0.65 |
| Biomass | 303.79 | 111566.42 | 53 |
| Small Hydro | 264.84 | 14053.44 | 6.7 |
| Solar PV | 252.29 | 61343.77 | 30 |
| **Total** | **932.60** | **208,455.75** | **100** |

The exploration of potential of energy generation from RE resources mainly from biomass has begun since year 2000 under 8th Malaysia Plan when the RE officially became the fifth fuel after oil, gas, coal and hydro [8]–[10]. The initial intention of exploration of this alternative energy was to diversify the national energy mixture in order to reduce the excessive use of fossil fuel, alleviate the effect of the global oil crisis while preserve the finite natural resources and increase the country energy security. RE is expected to contribute about 5% to the overall national energy mixture which was then dominated by gas and coal. Eventually, the RE function have been streamlined with the government intention to safeguard the environment when the Prime Minister announced the commitment to reduce greenhouse gas (GHG) intensity at a rate of 40% based on 2005 emissions level by 2020 [11]. Various initiatives have been taken to spearhead the development of RE technology in Malaysia since then and the national aspiration continues to received substantial support from the Malaysian Government. The Government become more optimistic to deliver 985 MW RE-based electricity by 2015 which is equivalent to 6% of the total electricity generation mix. The generation of electricity by biomass and biogas is expected to deliver 330MW and 100 MW respectively accounting for 44% of the overall targets. If implementation in accordance with the action plan had occurred, 11.1 million tonnes $CO_{2eq}$ could have been avoided in 2015, increasing to 42.2 million tonnes $CO_{2eq}$ when a cumulative RE capacity of 2080 MW by 2020 [12]. Ultimately, by 2030, the RE capacity is forecasted to reach 4000 MW which is equivalent to 163 million tonnes $CO_{2eq}$ avoided annually with substantial contribution from the palm oil biomass.

## 2.0 Biomass in Malaysia

Biomass energy can be extracted from the solid and liquid biomass resources including energy crop, forestry, agricultural and municipal waste, waste effluent, and manure and sewage sludge. These resources are used for their energy content to produce greener products or services such as biofuel, bioenergy, biomaterials and biochemical [13]. The global annual mass and energy availability from biomass is projected at 146 billion tonnes and 1150 exajoules (EJ) respectively [14]. From this amount, 359 million tonnes of biomass which is approximately 7.2 EJ were available in South East Asia [15]. In Malaysia, the amount of available solid biomass resources including but not limited to palm oil biomass, rubber and rice husk is 168 million tonnes with an energy content of 3.4 EJ [16]. The total land area of Malaysia is approximately 329,740 $km^2$ and 78700 $km^2$ is reserved as agriculture land. The agriculture area is composed of 16.3% permanent crops and 63.4% forest areas [17]. Tables 2 and 3 present the quantity of biomass produced with its energy generation potential and cumulative energy value in 2011 [18].

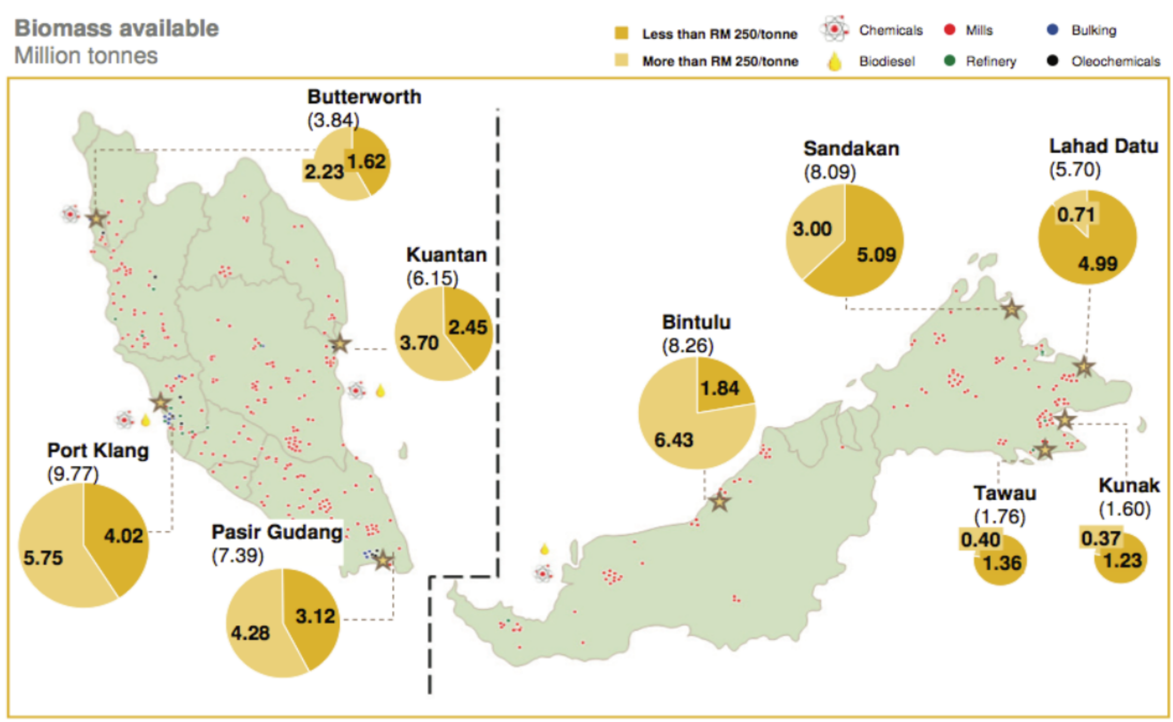
Table 2 Biomass Produced and Potential Energy Generation in Malaysia [19]

| Sector | Quantity (kton/year) | Potential Annual Generation (GWh) | Potential Capacity (MW) |
|---|---|---|---|
| Rice Mills | 474 | 263 | 30 |
| Palm Oil Mills | 17980 | 3197 | 365 |
| Palm Oil Mills Effluents | 31500 | 1587 | 177 |
| Wood Industry | 2177 | 598 | 68 |
| Baggage | 300 | 218 | 25 |
| **Total** | **79962** | **5863** | **665** |

Table 3: Cumulative Energy Value of the RE Resources

| RE Resources | Cumulative Energy Value (mil US$/year) |
|---|---|
| Biomass | |
| Forest Residues | 2,432 |
| Oil Palm Residues | 1,464 |
| Municipal Waste | 39 |
| Rice Husk | 16 |
| **Total** | **4,744** |

Oil palm biomass availability in Malaysia is more than 25 Million dry tonnes and readily to be mobilized across Malaysia at competitive cost by 2020 [16]. Figure 1 is showing the distribution of the oil palm biomass available throughout Malaysia with the processing plant. The distribution mainly can be seen throughout the peninsular of Malaysia due to the developing area and widely distributed biomass production comparing to Sabah and Sarawak. The highest area under the cultivation oil palm is in the state of Sabah with more than 1.2 million hectares. This is almost thirty percent of the total area planted under oil palm in Malaysia. The next highest state with oil palm cultivation is Johore, which has almost 700,000 hectares. The third highest oil palm growing state is Pahang with more than 600,000 hectares, next comes Sarawak with 591,000 hectares, followed by Perak with 348,000 hectares. The states with more than 100,000 hectares are Terengganu, Negeri Sembilan and Selangor, while Kelantan, Kedah and Melaka cultivate at ranges between 100,000 and 50,000 hectares. The states with smallest hectares are Pulau Pinang (14,000 hectares) and Perlis (258 hectares) [16].




Source: National Biomass Strategy 2020: New wealth creation for Malaysia's biomass industry (Version 2.0, 2013)

Figure 1 : Biomass availability in Malaysia

Oil palm has become one of the most important non-wood lignocellulosic materials for various types of products. The residue from almost every stages of oil palm processing has been proven to have the potential of use as biomass including oil palm frond (OPF), trunk (OPT), empty fruit bunch (EFB), palm kernel shell (PKS), palm mesocarp fibre (PMF) and palm oil mill effluent (POME) [20]. The OPFs account for 70% of the total oil palm biomass produced, while EFB accounts for 10%, and OPT accounts for only about 5% of the total biomass produced [21]. According to Sumathi et al., (2008), EFB and PMF are the highest contributors of oil palm biomass, whereby about 15.8 MT and 9.6 MT, respectively, are generated annually [9]. Recently, Loh (2017) claimed that the replanted areas for palm oil is estimated at 96,584 ha [22]. Reported by Ng et al., (2017), palm-based biomass depending on their calorific values between 6 to 20 MJ/kg having energy generation potential up to 1260 MW that is close to the maximum electricity demand in Malaysia [23]. With this reported potential, biomass from oil palm industries has a crucial role to play in achieving national and global agenda towards more sustainable electricity supply system. According to the Malaysian Palm Oil Board (MPOB), there were approximate 4.9 million hectares of matured oil palm plantation across the country in 2015 and increased to 5.2 million hectares in 2018 (Table 4). About 53% of the total plantation area are in Sabah and Sarawak yielding an average of 1.6 tonnes fresh fruit bunches (FFB)/hectares plantation. These plantations are owned by private estates (61%), government agencies (17%) and independent smallholders (22%) [83,136]. There are 235 active palm oil mills operated in Peninsular Malaysia with Pahang and Johor have the greatest number of mills, while 182 palm oil mills are operated in Sabah and Sarawak [83, 136].

Table 4: Oil Palm Plantation Area in Malaysia

| State | Plantation Area (million hectares/year) | | | |
|---|---|---|---|---|
| | 2015 | 2016 | 2017 | 2018 |
| Peninsular Malaysia | 2.3 | 2.3 | 2.4 | 2.4 |
| Sabah and Sarawak | 2.6 | 2.7 | 2.7 | 2.8 |
| Total | 2.9 | 5.0 | 5.1 | 5.2 |

Furthermore, Paddy is second largest crops with approximately 517,586 hectares of land in Peninsular Malaysia. The paddy cultivation area is concentrated in Kedah and Selangor with the overall paddy yield of 4,527 kg/ha producing about 1.8 million tons of rice in 2017. The production of rice produces about 3.66 million tons of paddy residues, which consists of paddy straw and rice husk which normally left on the field for natural biodegradation. This value is forecasted to increase to 7 million tons annually in 2020 due to the emerging technology in agriculture industries. With consistent increment trend in the amount of available paddy residues, it has high potential to be used as a feedstock for electricity generation. Generating electricity from paddy residues has been reported to address open burning issues and mitigate $CO_2$ emission. Statistically, generating electricity from rice straw and husk emits a total of 0.217 $kgCO_2/kWh$ and 0.43 $kgCO_2/kWh$ respectively, lower than $CO_2$ emissions from the conventional coal power plant in Malaysia.

Although less reported, the residues from coconut and sugarcane are also has a potential as the biomass resources. The residues from coconut trees are generated during the plant re-cultivation phase (i.e. fronds and debris). On the other hand, the residues from sugar cultivation are generated during the dry season and scattered around the northern states of Peninsular Malaysia. Next, the energy generation from rubber-wood is less significant than the other biomass, due to low availability, even though their cultivation area is the second highest after oil palm. The details of these plantations are well described in vast literatures [24,25,26]. Although huge amount of wood is harvested from forestry, only about 60 to 65% of the residues is considered available for energy generation while the remaining are either left for natural biodegradation or disposed in open burning. Currently, the residues are used mainly in pulp and paper industries. However, higher credit should be given to this wood products since it has higher energy potential and harnessing this potential for renewable energy purposes is highly demanded [27].

Recently, the Napier grass (NG) has gained more attention from the researchers. Studied have acknowledged that NG as a suitable resource to be used in sustainable electricity supply system owing to its performance advantages including high dry matter, yielding capability and wide propagation. NG is a tall species of perennial tropical grass that is stout, deep-rooted, and requires low water and nutrient for growth. It was first introduced to Malaysia in the 1920s and many of its species are presently cultivated across the country such as Taiwan Napier, King Grass, Dwarf, and Red Napier [28]. The yield of NG in different regions was assessed by Negawo et al., (2017), as enlisted in Table 5 [29]. In recent years, Malaysia has become among the top countries to invest on NG cultivation. NG was reported as having considerable potential to produce high yield of biomass approx. 100 boe/ha (barrel of oil equivalent per hectare), and can be harvested four times a year [30]. The output energy from NG is estimated as 25 times higher than the input energy consisting of high amount of lignocellulosic material. These advantages give credit to NG as a great source for bio-energy production as compared to other residues particularly through thermochemical conversion [31].

Table 5: Yield of Napier Grass in Different Countries [29]

| Country | Dry Matter Product (Tonne/Hectare/Year) |
|---|---|
| Bangladesh | 14.9–16.5 |
| Malaysia | 43.7–65.9 |
| Brazil | 14.9–78 |
| Ethiopia | 4.6–20.5 |
| Kenya | 12.1–19 |
| Thailand | 27.1–58.4 |
| USA | 27.1–58.4 |
| Zimbabwe | 90.2 |

### 2.1 Biomass Composition and Properties

The characteristics of raw materials such as elemental composition, volatile matter, fixed carbon and moisture content are greatly varies in different types of biomass [28]. The proximate and ultimate analysis of most common feedstocks in Malaysia and those of used in this literatures presents in Table 6. In biomass gasification, high volatile matter of feedstock results in high yield of syngas and less production of char which both are considered as process efficiency indicators [29]. Volatile matter is referred to substances release from the biomass in form of gas or vapour as it undergoes thermal conversion in the absence of air. On the contrary, moisture content of biomass is usually considered troublesome as it contributes to difficulties in handling, storage due to putrefaction and transportation cost due to higher density of biomass. The biomass with high moisture content (above 40%) significantly reduce the efficiency of thermal conversion as it consumes additional energy for drying the biomass prior to the pyrolysis process [30,31]. On the other hand, the elemental composition of biomass i.e. carbon (C), hydrogen (H), sulphur (S), nitrogen (N), and oxygen (O) are determined from the ultimate analyses. McKendry (2002) stated that the biomass with lower nitrogen and sulphur content has lower emission level while higher oxygen concentration reduces the biomass lower heating value. [32].

Table 6: Proximate and Ultimate Analyses of Different Biomass

| Property | Wood stem [33] | Paddy straw [33] | Rubber wood saw dust [34] | Coconut shell [35] | Palm kernel shell [35,36] | Napier Grass [25] |
|---|---|---|---|---|---|---|
| Moisture (wt.%) | 8.7 | 7.2 | 2.25 | 4.89 | 7.95 | 7.36 |
| Calorific value (MJ/kg) | 17.33 | 18.73 | 18.30 | 16.07 | 22.96 | 16.57 |
| Proximate analysis (dry basis, wt. %) | | | | | | |
| Volatile matter | 68.8 | 56.3 | 51.38 | 30.62 | 72.46 | 85.16 |
| Fixed carbon | 10.6 | 15.3 | 14.27 | 26.41 | 18.55 | 8.45 |
| Ash content | 0.3 | 20.8 | 22.68 | 42.98 | 8.96 | 6.33 |
| Ultimate analysis (dry basis, wt.%) | | | | | | |
| C | 50.51 | 48.74 | 53.40 | 45.24 | 51.62 | 45.2 |
| H | 5.8 | 5.97 | 6.70 | 5.04 | 5.51 | 5.92 |
| N | 0.22 | 1.98 | 3.10 | 1.46 | 1.88 | 1.43 |
| S | 0.11 | 0.28 | 0.00 | 0.06 | 0.04 | 0.34 |
| O | 43.43 | 45.27 | 36.80 | 48.20 | 40.90 | 47.16 |

In addition, ash properties also important during the conversion of these biomass samples. Ash refers to the inorganic powdery residue from burning the biomass under normal condition. The ash consists of silica (Si), calcium (Ca) iron (Fe), aluminium (Al), sodium (Na), magnesium (Mg), potassium (K), phosphorus (P), sulfur (S) and other metals and minerals [37]. Table 7 summarises the inorganic characteristics of ash produced from various biomass. Depending on the amount of metals and other minerals contents, this ash is suitable to be used as the soil amendment agent. However, higher production of ash and tar due to low temperature condensation has been a major disadvantages of gasification technology. Tsai (2012) indicated the formation of ash lowers the heating value of the produced gas.

Table 7: Inorganic contents of various types of biomass

| Ash basis (wt.%) | Wood [38] | Empty Fruit Bunch [39] | Rice Straw [40] | Miscanthus [33] | Napier grass [24] | Agricultural residue [35] |
|---|---|---|---|---|---|---|
| $K_2O$ | 15.80 | 44.00 | 8.80 | 14.00 | 54.39 | 1.65 |
| $Fe_2O_3$ | 7.80 | 3.00 | 0.18 | 2.63 | 15.53 | 2.95 |
| $SiO_2$ | 42.90 | 27.00 | 68.42 | 62.21 | 9.81 | 89.57 |
| Cl | - | 5.30 | 2.10 | - | 8.84 | 1.30 |
| CaO | 22.30 | 8.00 | 1.74 | 8.32 | 8.20 | 0.77 |
| $SO_3$ | - | 2.70 | - | - | 2.03 | - |
| MnO | - | 0.11 | 0.295 | - | 0.44 | - |
| $Rb_2O$ | - | 0.12 | - | - | 0.37 | - |
| Br | - | 0.018 | - | - | 0.14 | - |
| CuO | - | 0.039 | - | - | 0.10 | - |
| ZnO | - | 0.092 | - | - | 0.10 | - |
| $Al_2O_3$ | 3.60 | 0.97 | 0.31 | 5.47 | - | 1.32 |
| MgO | 1.80 | 4.80 | 1.69 | 3.16 | - | 0.76 |
| $Na_2O$ | 2.00 | 0.55 | 3.06 | 0.53 | - | 1.15 |
| $TiO_2$ | - | 0.08 | 0.02 | 0.32 | - | 7.56 |
| $P_2O_5$ | - | 3.60 | 1.34 | 3.37 | - | 1.04 |
| LOI | - | - | 13.36 | - | - | - |
| NiO | - | 0.01 | - | - | - | - |
| SrO | 3.8 | 0.03 | - | - | - | - |

**2.2 Spatial Mapping of Oil Palm Biomass Resources Potential**

Primary data are essential to better present the research output that can be used to foster the decision-making process. Nevertheless, obtaining the huge amounts of spatial and non-spatial crop data is a time, energy and cost intensive tasks. The emerging geospatial technologies such as Geographical Information System (GIS) and remote sensing has become a tool to map and manage the enormous amount of oil palm-related spatial data. GIS is a platform or framework for gathering, managing and analyzing spatial data. The data are organized in the form of layers and the information is visualized using maps and 3D scenes. The GIS is capable to operate using various types of data including satellite data, data collected for airborne sensors and waypoints collected in the field using handheld Global Navigation Satellite Systems (GNSS). With this unique capability, GIS allows researchers to identify problems and monitor any changes in the data patterns, apart from fostering decision-making process. The GIS is used in several studies to assess the land suitability for biomass plantations, biodiversity conservations, and land cover area estimations. The GIS-based technology offers essential support in decision-making, which is crucial in oil palm biomass applications [32]. The GIS is also used to analyse the available transportation network to determine the biomass hauling distances and cost [33], [34]. This analysis requires ancillary data including the transportation network boundaries (i.e. land and railroad) and population to be embedded into the GIS database [35]. Remote sensing data can then be integrated with the aforementioned ancillary data to help assist the GIS analyses [36,37].

Remote sensing is capable of providing geospatial data via various sensors. Up to now, advanced algorithms have been developed and tested on remote sensing data to classify the land cover and producing maps. Several studies have employed various sensors and algorithms to map the oil palm biomass resources potential [38-40]. Thenkabail et al. used multispectral IKONOS data to estimate the biomass content in the oil palm plantation [41]. Similar study on the estimation aboveground biomass was conducted in Sabah via Maximum Likelihood Classifier (MLC) supervised classification to classify ALOS PALSAR (Advanced Land-Observing Satellite Phased Array L-band Synthetic Aperture Radar) imagery. Forest and oil palm were classified, and from the allometric regression equations, the aboveground biomass was estimated [39]. Then, Morel et al. 2012 used similar approach via MLC on ALOS PALSAR and Landsat data to monitor the aboveground biomass in Sabah [42]. Koh et al., (2011) have established a closed canopy of oil palm plantations for Malaysia, Kalimantan, and Sumatera via 250 m spatial resolution imageries [43]. Then, Miettinen et al. (2016) produced a 2015 land cover map Southeast Asia at 250 m spatial resolution as well. Studies using LiDAR and Worldview-2 were carried out using high resolution data to map crops using SVM [44]. Studies have recommended that the very high-resolution data are more effective for crops identification [35]–[37]. Nevertheless, high-resolution data will be expensive particularly to large areas. On the other hand, many open data (i.e. Landsat 8, Sentinel-2, Sentinel-1, and MODIS) allowed the implementation of radar and multispectral data combination. Studies using this combination technique exhibited exceptional outcomes of biomass crops mapping and distribution. The radar data with multispectral data combination able to complement each other and improve the classification accuracy [25,42-44]. Although there are various available remote sensing and GIS data, accurate and up-to-date mapping of biomass resources potential remains a challenging task, especially in areas that consist of forest composite structure and other environmental conditions. Even though data combination displayed satisfactory results, selection of suitable algorithms and methods is crucial for biomass resources mapping at a desired scale [42], [43]. Furthermore, further analysis related to biomass study, such as determining land suitability for oil palm biomass plantations, transportation cost estimation, and area measurement for oil palm biomass resources potential are implementable within the GIS environment [44], [45].

Advanced machine learning algorithms, such as Support Vector Machine (SVM), Artificial Neural Network (ANN), Naïve Bayes, Decision Tree (DT), and Random Forest (RF) to be used with various sensors (i.e. Landsat, MODIS, and ALOS PALSAR) were identified as a suitable approach to differentiate the oil palm plantation distribution with other crops. Table 8 shows the studies done on oil palm using various classification methods via machine learning algorithms.

Table 8: Oil Palm Studies via Machine Learning

| Algorithm | Applications and representative literature |
|---|---|
| SVM | Performed image classification to classify oil palm and other land covers by comparing SVM with Minimum Distance (MD) [45]. Classification oil palm, rubber, forest and due to complex image, the classification results showed that SVM outperformed MLC [46]. Object-based Image Analysis (OBIA) was used to count and estimate the age of the oil palm tree [47]. Classification using different kernels was applied to classify nutrients in oil palm leaves [48]. |
| RF | RF was found to be the best algorithm to classify oil palm plantation via Google Earth Engine (GEE) compared to MD and Classification and Regression Tree (CART) [49]. Classification of time series using Landsat Thematic Mapper (TM) and ALOS PALSAR was successful and the oil palm trees were able to be clustered into several groups of age via RF [50]. Study on basal stem rot disease detection in oil palm plantations via RF model achieved the highest accuracy and the best result compared to SVM and CART models [51]. |
| DT | Study in the Sud Province of the Republic of Cameroon to classify oil palm, forest, water, and others was applied using the best algorithm via DT, followed by SVM, and an unsupervised algorithm, K-Means [52]. Comparison between pixel-based and OBIA was applied to produce land cover maps [53]. |

Mapping oil palm plantation via machine learning algorithms with remote sensing data is leading to a successful result. The hyperparameters in the algorithms can be tuned and optimised to improve the results. However, additional time and high computational power are required to finish the processing huge data in a software. Therefore, there is a cloud computing platform that can perform land cover mapping via machine learning efficiently [54,55].

There are number of approaches available to obtain oil palm information via remote sensing that resulted in less effort, time and cost. Moreover, the acquired remote sensing data can be processed and integrated with GIS data to perform further analysis.

Thenkabail et al. (2004) developed biomass models to calculate the carbon stocks level. The utilisation of IKONOS imageries with 4 m of spatial resolution were able to discriminate the oil palm trees into several groups of age and estimated the biomass content [56]. Multi-temporal Landsat 5 TM and Landsat 7 ETM+ (Enhanced Thematic Mapper) data were used to classify oil palm, oil and gas, forest and others in ENVI software. From equations and GIS datasets, the $CO_2$ emission was calculated, and the changes of the land use were observed [57]. Next, Forkuo and Nketia (2011) conducted a study to identify crop-land suitability in the Adansi West District. They used several important attributes that are related to spatial data to create soil geodatabase model and finally runs the crop-land suitability analysis to identify places that are suitable to plant crop [58]. Similar approach was carried out to detect the suitability of oil palm growth in Malaysia and Indonesia via climate change model [59].

The aforementioned studies on remote sensing and GIS have agreed that the integration of remote sensing data and GIS has improved the analysis and act as a complement each other and hence, the product will be beneficial in decision making. Figures 2 and 3 are the geospatial-based image representation of Peninsular Malaysia and Sarawak gathered from the comprehensive land evaluation process to evaluate the land characteristics, forest and plantations, road and drainage networks, water coverage and the built-up infrastructure. Such information is useful for current resource observation and management, and beneficial for future resource planning, monitoring and development.

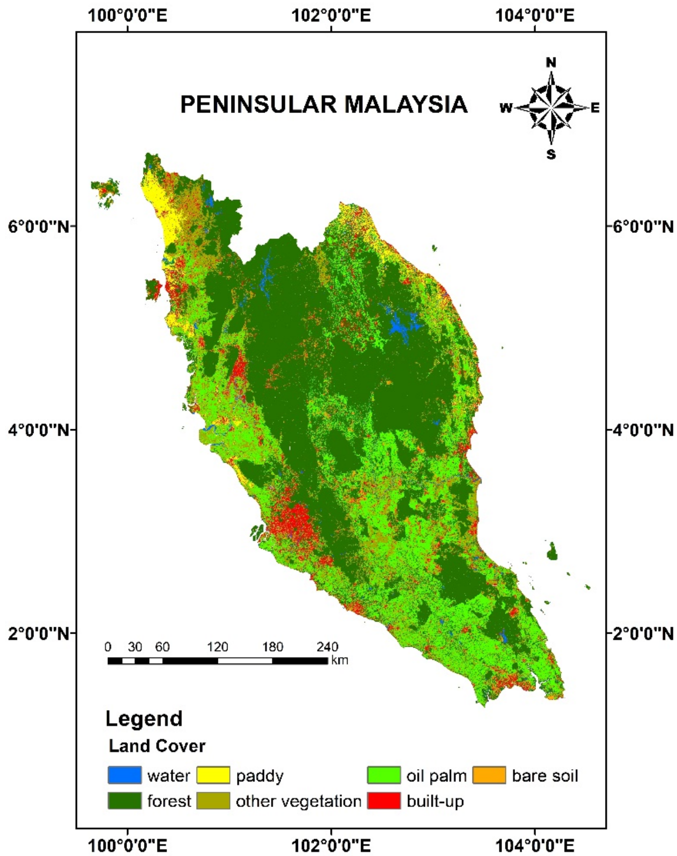



Figure 2: Geospatial-based image of Peninsular Malaysia

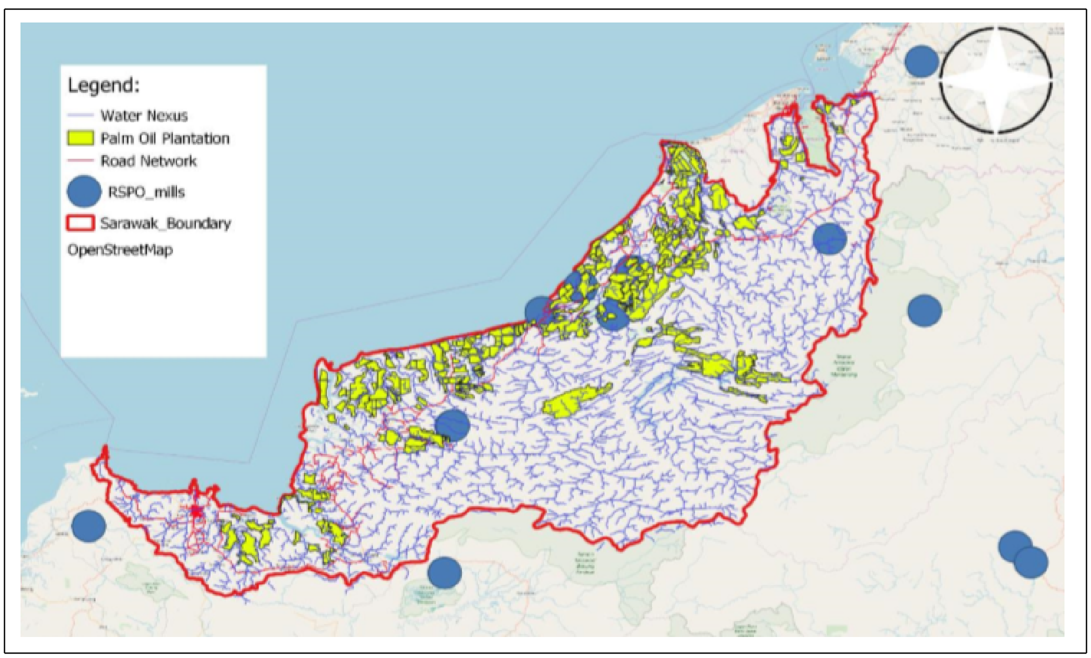



Figure3: Geospatial-based image of Sarawak

## 2.3 Technology Readiness Level

Biomass is one of the oldest renewable resources that provide energy sources and help to create renewable products such as biofuel, bioenergy, biomaterials and biochemicals [60,61]. The energy provided by biomass resource can be extracted through thermo-chemical process by heating and refining the resources into combustible liquid fuels and through biochemical processes by using enzymes, microbes and catalysts to make fuels. Numerous published studies have described the functionality of the various technology used in GT and RE to produce renewable products [62-75]. These studies evolve on asserting the functionality and assessing the feasibility of the technology and proving of concept stage (i.e technology readiness level 3). Table 9 summarized the currently available GT and RE technology.

Table 9: GT and RE Conversion Technology

| **Thermal conversion** | | | | | | |
|---|---|---|---|---|---|---|
| No | Feedstock | method | Study Parameters | Target | Improvement / Remarks | Reference |
| 1 | Wood residue | Steam gasification | AFR, time, T, dp | Highest $H_2$, Lowest tar | Highest AFR, T, time, Lowest dp | (Fremaux et al., 2015) |
| 2 | Coal | Steam gasification | P. $[H_2O/C]$, $[CaO/C]$, T | Highest $H_2$ | CaO as $CO_2$ sorbent | (Wang et al., 2014) |
| 3 | Sawdust | Steam gasification | P, $[CaO/C]$, $[H_2O/C]$, T | Highest $H_2$ | pressurized gasification | (Han et al., 2013) |
| 4 | Pine wood | Steam gasification | Fe/olivine catalyst | Tar reduction | Fe/olivine has double effect | (Virginie et al., 2012) |
| 5 | Risk Husk | Steam gasification | SFR,T | Syngas composition | H2 increases beyond CBP | (Loha et al., 2011) |
| 6 | Paper sludge | Air gasification | T, dp, static bed height, air flow | LHV, CGE | Minimized deviation from equilibrium | (Cordiner et al., 2012) |
| 7 | Napier grass | Air gasification | ER, T, SBH | Highest $H_2$, LHV, Syngas | Autothermal system | (Khezri et al., 2019) |
| 8 | EFB | Air gasification | ER,T, particle size | Highest $H_2$ | ER has highest effect on composition | (Mohammed et al., 2011) |
| 9 | PKS | Air gasification | T,P,SFR | Highest $H_2$, lowest Tar | Improve with Highest T, Lowest SFR | (Ng et al., 2013) |
| 10 | Sago barks | Fast pyrolysis | $N_2$ flow, T, time | Carbon rich biochar as solid fuel | High burning profile. Low emission of $CO_2$ | (Rambli et al., 2019) |
| 11 | rape straw | Fast pyrolysis | T, HHV | Bio-oil | highest yield of bio-oil at lower temperature | (Gómez et al., 2018) |
| 12 | corn stover, vine shoots, olive mill waste | Slow pyrolysis | T, P, atmosphere | biochar | pressurized slow pyrolysis under $CO_2$ atmosphere | (Manyà et al., 2018) |

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | cotton stalk, wood sawdust | dry torrefaction (DT), hydrothermal treatment (HT) | T | charcoal briquette | mass densities and compressive strengths of HT charcoal briquettes are better than those of DT | (Wu et al., 2018) |
| 14 | municipal solid waste | Combustion | ignition delay time, rate, mass conversion rate | Validated CFD model for biomass combustion | Model estimated the structure of moving fuel bed, overbed gas temperature, composition | (Mätzing et al., 2018) |

AFR: Air to fuel ratio; SFR: Steam to fuel ratio; T: temperature; ER: equivalence ratio; EFB: oil palm empty fruit bunch ; SBH: static bed height; CBP: carbon boundary point; PKS: Palm kernel shell

**Biological conversion**

| No. | Feedstock | method | Study Parameters | Target | Improvement / Remarks | Reference |
|---|---|---|---|---|---|---|
| 1 | acetone-butanol-ethanol-water mixture | Fermentation / steam reforming | T, P, steam/fuel ratio | Hydrogen | Best operating condition for maximizing $H_2$, suppression of $CH_4$, inhibition of solid carbon | (Kumar et al., 2018) |
| 2 | carbohydrates | fermentation | NA | Bioethanol | Hydrolytic and thermochemical treatments were described and compared | (Kennes et al., 2016) |
| 3 | broth | fermentation | Lactate and acetate concentration | Lactic acid | Higher acetate concentration promoted a more diverse lactic acid bacteria population | (Khor et al., 2016) |
| 4 | Microalgae | fermentation | T, acid concentration | Bioethanol | combination of organosolv treatment with enzymatic hydrolysis yielded comparable amount of sugar with hydrothermal acidic hydrolysis | (Chng et al., 2017) |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | *Lantana camara* | Fermentation/Enzymatic hydrolysis | T, time, $H_2SO_4$ concentration | Bioethanol | Developed a fermentation system with yeast strains capable of fermenting both hexose and pentose sugars simultaneously | (Kuhad et al., 2010) |
| 6 | Maize, winter wheat, triticale , winter rye, sunflower | anaerobic digestion | suitability of crop, variety, harvest time | methane | The highest methane yields were achieved from maize varieties | (Amon et al., 2007) |
| 7 | municipal plant waste | anaerobic digestion | lignification and crystallinity of cellulose | methane | lignin contents greater than 100 g/kg VS was resulting in low $CH_4$ potentials | (Triolo et al., 2012) |
| 8 | sorghum and napier grass | anaerobic digestion | lignin, cellulose and ash contents, total and volatile solids, total carbon | methane | lignin content was reported to be the most important factor affecting $CH_4$ production | (Sawatdeenarunat et al., 2015) |
| 9 | food industry wastes | microbial synthesis using activated sludge | different biomass | bioplastics | The use of activated sludge to convert carbon sources into bioplastics may also solve the disposal problem of municipal activated sludge | (Wong et al., 2000) |
| 10 | OPF | fermentation | Production cost | bioplastics | the production cost of bioplastics from OPF is practical and appropriate | (Zahari et al., 2015) |
| 11 | Microalgae | supercritical extraction of | T,P, solvent ratio | docosahexenoic acid (DHA) | 33.9% of lipid yield and 27.5% of DHA content were achieved | (Tang et al., 2011) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | lipid/transesterification | | | | |
| 12 | Microalgae | supercritical / hexane extraction of lipid | T,P and mass transfer | biodiesel | for supercritical extraction decreasing temperature and increasing pressure resulted in increased lipid yields. | (Halim et al., 2011) |
| 13 | Jatropha curcas (JC) seed cake waste | Catalytic effect to reduce free fatty acid (FFA) content | T, time, methanol/oil ratio, catalyst loading | biodiesel | conversion of FFA reached 99.13% under optimum conditions | (Mardhiah et al., 2017) |
| 14 | wet yeast | microbial lipid extraction | T, time, detergent concentration | detergent assisted lipids for biodiesel | oleaginous yeast biomass treatment with N-lauroyl sarcosine would be a promising approach for industrial scale microbial lipid recovery | (Yellapu et al., 2016) |

T: temperature; P: Pressure; OPF: oil palm frond

## 3.0 Biomass-based Electricity Generation in Malaysia

The electricity generation landscape in Malaysia evolved since the formulation of the National Energy Policy 1979 that emphasized the adequacy of the supply, promotion of energy efficiency and protection of the environment. This was followed by the introduction of the Fifth Fuel Policy under 8th Malaysian Plan for 2001 to 2005. This policy aimed to diversify the national energy mix by introducing RE resources as the fifth fuel after oil, gas, coal and hydro. The newly introduced energy resources were expected to contribute 5% to the national energy mix with 500 MW of green electricity connected to the national grid [11]. Many initiatives have been taken to promote and to attract the private sector to invest in the electricity generation business in Malaysia under the Small Renewable Energy Programme (SREP). Under SREP, electricity generated from RE resources by the licensed producers can be sold to the distribution licensee through the distribution grid system. The licencing duration is 21 years from the date of the commissioning of the plant. A Special Committee on RE (SCORE) was formed to oversee the process and is supervised by the Energy Commission (EC). With a very slow pace of development, only 12 MW of electricity had been exported to the national grid in Peninsular Malaysia by December 2005. To supersede the missed target, progressive action was taken by the Government to continue the 5th Fuel Policy in the 9th Malaysia Plan (2006-2010) alongside the 40% carbon intensity reduction commitment from 2005 levels by 2020. The target for RE electricity generation capacity in Peninsular Malaysia was also revised downwards from 500 MW (Fifth Fuel Policy) to 300MW. The transition towards greener electricity was elevated with the formulation of the Green Technology Policy 2009 that gave a clear direction towards low carbon and renewable energy electricity [11]. As of 31st December 2010, 68.45 MW was dispatched to the national grid [76].

Five strategic thrusts were outlined to facilitate the National RE Policy 2010 consisting of introduction of appropriate regulatory framework, provision of a conducive business environment for RE, intensification of human capital development, enhancement of RE research and development and implementation of a RE advocacy programme. Among these, the introduction of the RE Act 2011 and the feed-in tariff (FiT) mechanism can be considered as particularly useful. This Act provides an extensive roadmap to deliver the generation of RE electricity by introducing an attractive tariff payable to the licensed producers who also receive a priority of purchase and distribution from the licensees. Taking a small-scale biomass- and biogas-based electricity generation plant as an example, the FiT that have been offered are RM 0.32/kWh and RM 0.31/kWh respectively for a period of 16 years with an annual digression rate of 0.5%. The licensed producers may gain an additional bonus rate depending on the process efficiency level besides the usage of local manufactured and assembled technology. Even though it has undergone tremendous improvement over the last 15 years, as of 20th May 2014, a total of only 188.33 MW of RE power plant capacity has been installed [77].

The Malaysian Government continued the to drive the national aspiration by introducing the National Biomass Strategy 2020 (NBS 2020) in November 2011. This initiative aims to investigate the possible ways for Malaysia to utilize its biomass from palm oil industry and to be benefitted from the associated additional revenue. This strategy is driven from an extensive collaboration between the stakeholders including the Malaysian government, private sectors and local and international research institutes. The focus of the strategy is to improve the biomass value chain which is estimated to have a value of USD 72.5 billion, create about 66000 employment opportunities, generate approx. USD 6 billion of investments and reduce 12% of national carbon emissions. Although it was intentionally for palm oil biomass, NBS 2020 is also covering different biomass types such as wood, rubber and rice husk. The enhanced version of NBS 2020 (released in 2013) has included the forestry biomass and dedicated crops to accelerate the results of the strategy and to increase the downstream value of the industry. Among the issues, the resource availability, mobilisation costs, and downstream supply potential are getting the most attention in the strategy.

An overview of policies and action plans related to the biomass industry in Malaysia is given in Tables 10 and 11, respectively.

Table 10: Overview of Various Malaysia's Biomass Policy

| Policy | Year | Rationale/Objective | Enabler/Implementation | Outcome/Result |
|---|---|---|---|---|
| National Biotechnology Policy | 2015 | - Develop Malaysia as a key player in the global biotech sector due to Malaysia's rich biological resources and diversity. | -Establishment of Biotechnology Corporation Malaysia to oversee the implementation of the plans and actions. | -Positioning of Malaysia as favourable location of investment to attract foreign technology providers.<br>-Higher demand for biomass feedstock in Malaysia as well as the awareness of the potential of biomass for Malaysia's industrial growth in the future. |
| National Green Technology Policy | 2009 | - Stimulate green technology as a new driver for the nation's economic growth in addition to sustainable development.<br>- Develop and promote the implementation of 'green' or sustainable technology in 4 sectors (energy, building, waste & water management and transportation) | -Provision of Green Technology Financing Scheme worth USD 1 billion for companies to undertake 'green' projects.<br>-Investment and tax incentives as well as setting of Green Tech Corporation to promote and facilitate the green tech industry. | -Encourage the production as well as the utilisation of RE from waste biomass.<br>-Promote the establishment of biomass fuel pellet production plants for export markets.<br>-Promote the utilisation of biomass for manufacturing of high-value products for the building and transportation sectors.<br>-Promote the utilisation of municipal solid waste and other organic waste for biogas production and RE generation.<br>-Create the pull effect on biomass-related technologies and investments into the country. |
| National Renewable Energy Policy and Action Plan | 2009 | -Enhance the utilisation of indigenous RE resources to ensure energy security in tandem with contribution towards sustainable socioeconomic development. | - Passing of Renewable Energy Act 2011.<br>- Implementation of feed-in-tariff (FIT) mechanism.<br>- Provision of RE fund.<br>- Formation of Sustainable Energy Development | - Create a larger demand pressure on local biomass resources.<br>- Promote the development of local technologies and know-how in bioenergy sub-sector.<br>- Promote the investment and financing in biomass-related projects. |

| | | | | |
|---|---|---|---|---|
| | | | Authority (SEDA) to implement the policy. | |
| Biomass Industry Strategic Action Plan (joint program between EU and Malaysia) | 2010-2013 | -Assist the small and medium enterprises (SMEs) in Malaysia to exploit local biomass resources for high-value utilisation. | - Formation of the Biomass Industry Strategic Action Plan 2020 to develop the whole biomass industry in Malaysia.<br>-Formation of the Malaysia Biomass Industry Confederation (MBIC) which is initiated by the biomass players in the industry especially the SMEs. | - Unlock biomass feedstock for downstream utilisation through optimising the efficiencies of resource utilisation upstream.<br>-Smart utilisation of biomass for high value production through commercialisation and scaling-up of local know-how as well as expertise and setting of market-focused Biomass Smart Hubs.<br>-Position Malaysia as regional and international biomass hub by establishing the nation as the focal point for biomass stakeholders. |
| National Biomass Strategy 2020 | 2011 | -Economise the mobilisation of biomass resources from the field as well as the impact on the soil fertility of the removal of biomass from field. | -Creation of the Oil Palm Technology Centre to consolidate the required resources. | -High value utilisation of biomass resources which contribute to annual gross national income. |

Table 11: SWOT analysis on Malaysia's renewable energy policies

| **Strengths** | **Weaknesses** |
|---|---|
| Intention to involve in sustainability programs<br>Availability of comprehensive approaches<br>Strong and clear objectives to accomplish<br>Wide-reaching international Collaborations | Absence of regulatory framework<br>Insufficient finance and lacking knowledge<br>Inadequate fundamental research<br>Lack of public support<br>Insufficient statistics pertaining renewable energy |
| **Opportunities** | **Threats** |
| Globally increase of renewable energy contribution<br>Increase employment rate<br>Lessen the dependency on conventional fossil-based fuels<br>Increase in energy efficiency | Occasional altering of international renewable energy standards and policies<br>Renewable energy technology change<br>Public discontentment and disapproval<br>Political conflicts<br>Economic issues |

Various studies have been conducted to review the policies and initiatives of RE in Malaysia. Chang, Fang and Li (2016) acknowledged the comprehensiveness of these policies and action plans, however, the study indicates that they are found to be disassociated from one another. Such disassociation has led to contradictory policy implementation pathways and discouraged the development of RE. Numbers of key barriers identified which limit the penetration of RE electricity in Peninsular Malaysia's electricity landscape. The primary barriers that need to be addressed include the electricity sales prices, RE purchasing agreement, financing assistance framework and lack of awareness from the public [78-80]. The studies agree that Malaysia is well equipped with a very extensive set of energy related policies and initiatives yet there is a gap between the policies and their real implementation [80]. Umar, Jennings and Urmee (2014) in their study confirm the importance of diversifying the energy resources towards sustainable electricity and acknowledged the survival of power generation system in Peninsular Malaysia may require an intermixture of short-term and long-term plans. The study found that refining the energy policy and the expansion of existing electricity generation capacity using abundance renewable energy resources must be clearly articulated in order to archive energy security at favourable cost and to mitigate carbon emission [78,80].

### 3.1 Available Incentives for Biomass Industries in Malaysia

In line with the institution of policies to accelerate the development of green technology (GT) and renewable energy (RE) in Malaysia, various incentives have been introduced to accelerate the uptake of the technology. The Feed-in tariff mechanism is aimed to incentivise the RE generators and to encourage the exploitation of RE in the country. Under this mechanism, the generators are eligible to sell the electricity generated to the electricity distribution company using fixed tariff for certain period of time depending on the types of biomass used as the feedstock to generate RE [80,81]. Furthermore, the GT and RE developers are also entitled to receive the capital allowances (CA) which consist of initial allowance and annual allowance. These allowances allow the developers to get tax relief on the qualifying capital expenditure. The initial allowance is fixes at the rate of 20% of the qualifying capital expenditure while annual allowance is given each year until it has been fully written off. In addition to CA, the Malaysian Government offers various range of investment tax incentives (e.g. investment tax allowance and income tax exemption) to further reduced the tax liability on the developers and to reduce the economic uncertainties of the projects [81]. Previously, the Malaysian Government has set up the Green Technology Financing Scheme (GTFS) to provide a 2% rebate on the interest rate charged by the financial institution and guarantee of 60% on the financing amount, with the remaining 40% of the financing risk to be borne by participating financial institutions [81]. However, GTFS has expired at the end of 2015 as scheduled. Despite having a range of incentives, it is incapable to provide sustainable and profitable investment returns to the developers [82,83]. In this respect, there is a need for a systematic study to revise and redesign more practical and realistic incentives with an aim of reducing the possibility for impractical GT and RE projects in Malaysia.

### 3.2 Climate Change Mitigation Action Plan

As a signatory to the Kyoto Protocol in 1998, Malaysia has pledged to reduce greenhouse gas (GHG) emissions to mitigate global climate change. To demonstrate the commitment towards preserving the environment, the Prime Minister proposed to reduce the national $CO_2$ emission by 40% from the 2005 level by 2020 at the Fifteenth session of the Conference of the Parties (COP 15). With this substantial commitment, transition to a low carbon economy is very important to enable Malaysia to reduce its $CO_2$ emission [84]. In the same study, it was stated that each of the economic sectors has to reduce the amount of $CO_2$ production at the rate of 4%

each year. The enthusiasm to reduce $CO_2$ emissions was indisputable when the Malaysian Green Technology Corporation (GreenTech Malaysia) was set up under the jurisdiction of the Ministry of Energy, Green Technology and Water to catalyze the adoption of GT and RE in Malaysia. GreenTech Malaysia plays a significant role in facilitating the National Green Technology Policy and NBS 2020 that aims to revolutionize the conventional electricity supply chain to a low carbon electricity supply chain to meet the global commitments to reduce GHG emission. This revolution is expected to avoid approx. 163 million tonnes $CO_{2eq}$ annually by 2030.

## 4.0 Functional Technology Models

To date, there are only limited examples of actual installation of biomass-based technology projects. More focus has been given to biomass-based electricity generation in line with the targets from various renewable energy and environmental protection policies. However, according to Yatim et al. (2017), biomass-based power generation has not yet achieved commercial maturity and remains at the proof of concept stage (TRL 3). The system still suffers from competitive pressure from conventional electricity generation sectors whereby it remains as an unprofitable system due to the high cost-intensive nature of the technology. Despite the mentioned issues, there are few functional technology models has been presented and brought forward to be developed at the pilot scale size [86-91]. However, the major issue that has dominated the discussion for many years is how to translate the technology models into actual implementation due to multiple economically unfeasible conditions [92]. Factors such as the remote geographical location of palm oil mills and limited existence of grid connection has become the traditional barriers for RE deployment. Umar, Jennings and Urmee (2014) acknowledged the lack of grid transmission lines connecting mills to the existing network system has led to lower export of electricity to the grid. It is reported that more than 63% of the palm oil mills located more than 10 km from the nearest grid point with 23.5% of these mills are located more than 40 km away from the nearest grid point (Umar, Jennings, and Urmee, 2014). That justify why most of the palm oil residues remain at the plantation to mulch as organic fertilizers. Some are burnt onsite with pericarp fibres and empty shells to produce industrial steam and electricity. Furthermore, since processed palm oil is exported by the use of ship tankers, it made sense that the refineries are located at the ports. Export of palm oil and its related products are through the available ports in West and East Malaysia, such as Penang Port, Lumut Port in Perak, Port Kelang in Selangor, Pasir Gudang in Johor, Kuantan Port in

Pahang,Kuching Port, Bintulu Port, Miri Port and Sabah Port. Generally, a mill, which receives 400 tonnes of FFB daily, produces about 170 tonnes of CPO. Some private mills do have their own tanker lorries, but the capacities of these lorries are rather small, something between 15 to 25 tonnes. So, if the mill uses only the 25 tonnes lorries, we expect to see some 8 lorries loaded with CPO leaving the mill to the refineries in a day. As for the Palm Kernel shell (PKS), about 40 tonnes are gathered daily. Usually the PKS is not transported out daily because the PK do not go bad upon storage at room temperature, unlike the CPO which need to be processed immediately. The PK usually gets loaded in 40 feet open trailer, which can carry some 30 tonnes of the byproduct. If the PKS is accumulated for 3 days then we can see 4 such trailers leaving the mill for the crushers the next day. Furthermore, restricted access to the technology, less suitability of the imported technology to be used with local biomass feedstock, lack of skilled personnel, and lack of operation and maintenance facilities has been described as the factors limit the functionality of the biomass-based power generation technology [17,25,136].

Despite all the barriers, Umar, Jennings and Urmee (2014) revealed that 75% of the 85 respondents from the palm oil millers in Malaysia had expressed their interest to invest in RE generation business and collaborate with the government to contribute towards achieving the national renewable energy target when the technical and techno-economic performance of the project would be reasonable. Therefore, it is essential to justify the economic viability of the project to allow the detailed descriptions and estimation of potential costs, anticipated revenues and relative profitability of the system.

### 4.1 Techno-Economic Feasibility

Under the current development pace, studies claimed that the RE environment in Malaysia as ‘non-conducive’ for the RE generation business due to its unfavourable techno-economic feasibility. Alkemade and Hekkert (2012) stated that the speed, direction, and success of RE business development is highly dependent on the environment where it is implemented, rather than the deficiency of the energy conversion technology adopted. Most published works have described the combination of operational and financial barriers as the main ones hindering the development of POMR to RE generation technology in Malaysia [99,100]. RE technology is still perceived as high risk, unprofitable and less attractive. With this perception, absence of functional business model and lack of understanding on the financial requirement for the technology, most financial institution have enforced complex loan application processes in addition to high-interest rate [101,102].

Most of the proposed techno-economic models for generating electricity from biomass is developed based on the expert predictions and estimations derived from the literature and field observations. The installation cost for one-megawatt electricity generation capacity is estimated between RM 8 million to RM 10 million depending on the power plant scale while the annual fixed operational cost (e.g. maintenance, labours, plant overheads, capital charges, insurance, and taxes) of the power plant is estimated as 6% - 10% of the capital cost [86,93]. On the other hand, the variable operating cost (e.g. feedstock cost, feedstock transportation cost and utility cost) are depending on the scale of the power plant. The estimated cost of wet palm oil biomass was about US$ 4.50 – US$ 110 per tonne biomass [93,94]. Various methods have been used in literature to estimate the feedstock transportation distance and cost [95,96] and these costs have a significant influence on the economic feasibility of biomass-based energy system. The feedstock transportation cost using trucks was computed analogously using the Peninsular Malaysia's feedstock transportation cost linear equation as shown in Table 12 [97].

Table 12: Feedstock Transportation Cost Linear Equations

| Truck Size (tonne) | Transportation Cost Linear Equations |
|---|---|
| 1 | MYR/tonne = distance (km) x 1.89 + 132.00 |
| 3 | MYR/tonne = distance (km) x 0.67 + 69.10 |
| 10 | MYR/tonne = distance (km) x 0.26 + 49.30 |
| 26 | MYR/tonne = distance (km) x 0.19 + 39.50 |

Truck was commonly used as the feedstock transportation mode in Peninsular Malaysia since most of the mills are accessible on a paved road and trucks known to have a negligible economy of scale and have more stable distance variable component [98].

Based on the expert predictions on the cost incurred and revenue gained from biomass energy generation, Wan et al. (2016) predict that such system has positive return on investment within seven to eight years. Similarly, Chin et al. (2013) claimed generating electricity using biogas of POME in a palm oil mill (e.g. 60 t/hr FFB processing capacity) could save 3.4 million litres of diesel annually with the payback period of 4.5 years. Based on realistic estimation on available palm oil mill residues, Md Jaye (2019) predicts that generating electricity from EFB are more profitable than the other palm oil residues with lucrative net present value and competitive break-even point.

**5.0 Biomass, energy, food, environment and water (BEFEW) Nexus**

For centuries, biomass has been the primary energy source for humankind, mainly for cooking and heating. However, the demand for fossil resources has increased significantly in line with consistent population and economic growth. Over reliance on the fossil fuel resources are known to have negative impacts on the environment. The unpredictable weather conditions, noticeable eutrophication and poor air quality are among the impacts from the over reliance on the fossil resources. Evidently, these impacts direct and indirect effect on the access for food, energy, and clean water. For instance, the access for food, energy and clean water are limited during flood and drought. Besides the environmental issues, the limitation is due to the "in-silo" designs of the current food, water and energy provisioning systems often ignore the complex interconnection between these three sectors with the environment. Currently, to broaden the comprehension over such complex cross-sectoral interactions and to discern more sustainable solutions, the concept of *food-energy-water (FEW) nexus* is being adopted which was first presented at the 2011 Bonn Conference. The *FEW nexus* approach was used to explain the UN Sustainable Development Goals of encouraging integration across sectors for sustainable use of natural resources [103].

The urgent need to increase the energy supply in the transportation sector has increase the demand to use supplementary resources (e.g. biomass) for biofuel production. This situation has created a competition to use wheat, corn and oil crops for food and fuel. Such competition has directly increased the food price. It has triggered the food vs fuel debate especially on the food accessibility and affordability. Furthermore, the energy crops cultivation and biofuel productions requires large amount of water that may introduce water scarcity issues in certain locations [104]. For instance, the 2020's biofuel target in China has diverted about 5-10% of the cultivated lands for energy crops. It is further estimated that about similar amount of annual Yellow Rivers' annual water discharge is required in order to meet the target. Globally, biofuel contribute approx. 4% in the transportation fuel mixture, however the amount of water consume during the biofuel production represents 3% of the amount of the total water consumption. Additionally, the amount of feedstock used could feed about 30% of the population that suffered from food poverty [105]. Therefore, a systematic analysis on the interactions between all the competing components in the nexus is demanded in order to reduce the negative impact and to balance the trade-offs from utilizing biomass to produce biofuel [106].

The interlinking between water, energy and food resources have greatly drove the economic development in Malaysia and other Asia-Pacific countries. Biomass has greater potential to be considered as the renewable resources for long term sustainable development. As such, a comprehensive study on the implementation of biomass production system using the nexus approach is urgently needed. Multiple preliminary studies have been conducted in various ASEAN countries probing on the *FEW nexus*. These studies focusing on the high-level analyses with minimum consideration is given on the role of biomass in the nexus. The *FEW nexus* from the governance and policy perspective in thirty two Asia Pacific countries was analysed by Taniguchi et al., (2015) [107]. Endo et al., (2015) studied the *FEW nexus* by evaluating thirty seven selected projects including some in Asia. The nexus for the Hindu Kush Himalayan region was analysed using secondary data from diverse sources emphasising on the role of ecosystem services in sustaining food, water, and energy security [108]. A study on strategies to manage the cross-sectoral and transboundary impacts of the nexus was also carried out for the Mekong Region [109]. Most of the recent literatures reckoned the need to foresee a wider systems' perspective, consider the multiscale and multitemporal nature of a problem, and recognise multiple ways to manifest the nexus in different contexts, especially at the regional and local level. Researchers also agree on the urgent need for quantitative, flexible, and dynamic tools to support decision-making by providing clear indicators on the impacts of each technology, biomass feedstock, and policy instruments that capable to encourage a biomass-based economy. NexSym is a simulation tool recently developed that considers ecosystem components and their dynamics for quantitative analysis of flows across the FEW sectors; carbon and nitrogen emissions, as well as ecosystem services, such as biomass provision and carbon capture [110]. A proposal to integrate the ecosystem-water-food-land-energy (EWFLE) nexus concept into life cycle assessment has also been presented mainly using food as the central component [111]. The reviews on the methods, frameworks and tools for the nexus assessment are mainly found in the literature published in 2018 [112–114]. However, only a few studies have considered the three *FEW nexus* components in their optimisation framework [115,116].

To date, studies have superficially discussed on the nexus in Malaysia and how to maximise the contribution of the biomass towards the nexus. Statistically, the agriculture sector contributed 8.1% to the country's GDP in 2016. Oil palm was a major contributor at 43.1%, followed by other agriculture crops, including rice (19.5%), livestock (11.6%), fishery (11.5%), forestry (7.2%), and rubber (7.1%) [117]. The demand for water in Malaysia has increased steadily for agricultural, industrial, and domestic purposes, with the agricultural sector using 76% of all available water, while access to clean water is becoming an important issue in the country [118]. About 98% of water is sourced from rivers and reservoirs. It has been estimated that more than 100 million $m^3/y$ of water is used for energy generation in Malaysia, mainly contributed by thermoelectric power stations and the growth of biofuel-based power station, mainly from palm oil [119].

Palm oil is the most important agricultural commodity in Malaysia and plays a significant role in the development of bio-economy in the country. The palm oil industry uses 4.9 million hectares of planted area and receive strategic policies support, as well as research and development (R&D) activities from MPOB. The continuous expansion of oil palm plantations is expected in line with the government support and consistent demand for biodiesel from Europe and also for domestic use of 7% biodiesel blends (B7) in Malaysia. Some of the major projects under the Palm oil National Key Economic Area related to the food, energy, water and environment nexus include the development of biogas facilities to treat POME, commercialising second generation bio-fuels, expediting growth in the food and health-based downstream segments, and focusing on high value products generated from palm oil. The production of palm-based phytonutrients such as tocotrienol from Vitamin E family is an example of contribution from bioenergy production to the food security and health. The initiative to use B7 biodiesel blends in peninsular Malaysia has a substantial contribution of 439,000 tons of biodiesel annually. Nonetheless, realising these ambitious Malaysia plans will imply land conversions for biofuels, thus affecting food security targets including domestic rice production. Furthermore, this can affect carbon emissions and water security targets due to the subsequent deforestation and sedimentation. This clearly exemplifies the intricate correlations that demanded systematically and analytically studies to determine the trade-offs from the resources and identify the possible solutions to balance such trade-offs. Figure 3 illustrates an overview of the food, energy and water nexus of the oil palm industry in Malaysia.

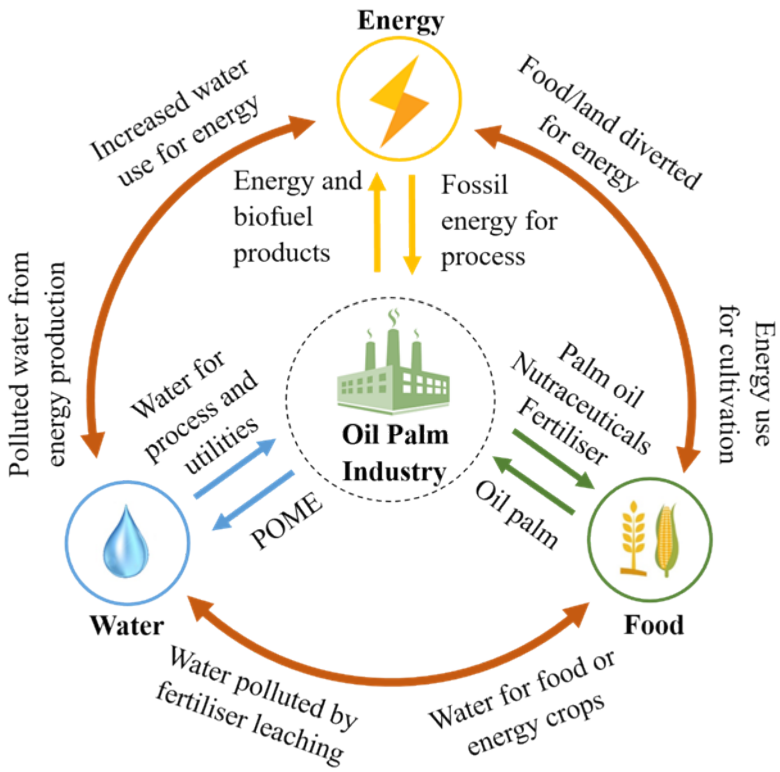



Figure 3: Overview of the food, energy and water nexus of oil palm industry in Malaysia

### 6.0 Future Direction: Digitization of the Agriculture Industry

The intensive growth of agricultural sectors in Malaysia was emerged during the 9$^{th}$ Malaysian Plan period emphasizing on transforming the conventional agriculture sector to becoming a modern, viable, dynamic and competitive sector. New strategies and polices has been set to expediate the transformation including promoting large-scale commercial farming and exploring various high-quality and value-added activities. These two strategies instill higher potential to enhance the productivity of agricultural sectors, generate higher income and assist agro-based processing and agriculture entrepreneur development [120]. Few government agencies (e.g. Ministry of Agriculture (MoA), Ministry of Plantation, Industries and Commodities (MPIC) and the Ministry of Rural and Regional Development (MRRD)) are assigned to oversee this transformation. Furthermore, under 11$^{th}$ Malaysian Plan, policies concerning on greater food security, growing more of the country's staples and relying less on imports have been institute to bring the sectors closer to those in the developed countries [120]. The institution of the policies has further emphasized on the advancement of agricultural technologies, marketing strategies, sustainability and production standards.

In the modern agricultural horizon, the farmers have a direct access to the digital information and are well expose to the current technology to observe the weather forecast, soil condition and crop health. This technology advancement is beneficial for the farmers with substantial improvement on the product yields are observed. The digital data with the help of binary codes has become the most significant and robust tool in modern agriculture. Recent automation technologies of the agricultural machineries such as tractors and digital sensors have already made huge impacts in plantation yields, soil quality and structure and field topography. Billions of relevant satellites data points are available to assist the farmers to increase their productivity and work efficiency. Furthermore, the climate-smart agriculture approach also has been introduced to the farmers to promote integrated solution for climate change mitigation and sustainable agricultural [121]. Under this approach, space technology derived instruments (i.e. gather information of sea plankton using satellite data), sensor enables plantation (i.e. plants telling the farmer how much water they had and when they needed more) and precision agriculture wireless network (i.e. to monitor field signals for precision agriculture) and climatic robotic (i.e. provide automated crop survey) are among the example of artificial intelligence integration in accelerating the future of agriculture sectors.

The integration of artificial intelligence (AI) and modern ICT is still at infancy stage in Malaysia's smart agricultural perspective. Few studies have assessed the way forward for various technology for instance using drones to provide real time information regarding the plantation area, and using internet of thing (IoT) to enable the farmers to enhance the productivity and manage waste [122]. Additionally, Abu Bakar (2019) assessed the usage of wireless internet and global positioning system (GPS) that is connected with drone, machinery and other farming equipment to manage the plantation area without visiting the farm. Table 13 provides detailed information regarding the integration of AI and modern ICT in agricultural industries in Malaysia.

Table 13: Integration of AI and ICT in agricultural industries in Malaysia

| No. | Types of Integration | Functionality | Reference |
|---|---|---|---|
| 1. | IoT Technology, Sensors and Actuators | Address the automation in the production by controlling the climate to expedite and accelerate the growth in mushroom cultivation | [123] |
| 2. | Wireless Sensor and Cloud Computing | Collect and process large amount of data from the beginning until end of the process loop | [124] |

| | | | |
|---|---|---|---|
| 3. | Fog computing | Control environment which permits product growth rate control and predictable harvesting schedule | [125] |
| 4. | Microcontroller, Mobile Application | Conduct a quick soil analysis, observe the results and dispense fertilizer on crops via a mobile application | [126] |
| 5. | IoT Technology | Provide a number of services to the farmers that include crop management, marketing, finance management, e-commerce, web services | [127] |
| 6. | Image Processing, Robotics | Provide solutions for Sarawak White Pepper grading using a combination of image processing technique and robotic automations to sort pepper berries into their respective grades | [128] |
| 7. | Image Processing, Mobile Application | Develop an expert system tool for evaluating the ripeness of banana fruit | [129] |
| 8. | Unmanned Ariel Vehicle, Image Processing, Sensors | Manage a farm properly to increase its yield | [130] |
| 9. | IoT Technology, WebGIS, Remote Sensing | Solutions for oil palm plantation including health assessment and disease detection, pest monitoring, yield estimation, creation of virtual plantations, and dynamic Web-mapping | [131] |
| 10. | Unmanned Ariel Vehicles, Sensors | Monitor and map the agriculture sector at large area payload by compact sensor and to identify the characteristics of rubber tree clone leaf diseases based on two groups of spectral wavelength | [132] |
| 11. | IoT Technology | Design of smart monitoring system using an embedded micro-web server, with IP connectivity for accessing | [133] |
| 12. | Wireless Sensor, IoT Technology | Deploy seamless monitoring and controlling system to minimize costs and maximize yields | [134] |

Although currently at its initial stage, studies have emphasized that the development of smart agriculture in Malaysia are rapid and progressive [135]. A sizeable progress has been charted despite a rising needs for wider integration of farmers' perceptions and levels of education, as well as extension-workers' knowledge to find a new approach to driving the plantation efficiency, improving operation, making smarter decisions, reducing cost and boosting productions [134]. Exploring the smart agriculture options by integrating IoT, image processing, wireless technology, big data and sensors and actuators are the way forward to accelerate the future of sustainable agricultural in Malaysia and as one of the mechanistic solutions for the Industrial Revolution 4.0 and Agriculture 4.0. Nevertheless, this technology advancement is worth nothing without institutional collaboration between government and private sectors. Various stakeholders have to come together to develop pilot projects and to conduct ongoing research and development efforts to create several plausible solutions for agricultural development and transformation. The clear challenges of the smart agriculture are to finding a way to transform the case studies finding to scaling up practices and getting policy-makers onboard to design a practical policy to best support and open the windows of opportunities for smart agriculture.

**7.0 Conclusion**

In summary, the progression of investment plans in agriculture gain great values while incorporated with BEFEW nexus towards sustainability in Malaysia. Comprehensive analysis approaches can be employed to identify the synergies in the nexus and to assess the associated benefits and trade-offs across the ecosystem of the service sectors. This would be possible only if all the strategies, policies and legislations have been coordinated and all related cooperation have been involved. In this regard, Malaysia is experiencing similar challenges faced by the other nations, however, the problems tend to diminish by using integrated approach in resource management at the regional level. The BEFEW nexus could be an excellent tool to mitigate the threat of inefficiency and mismanagement of the resources and to reduce the susceptibilities that permeate the region. Nonetheless, successful implementation of the nexus at a regional level requires commitment from government, supported by technological innovations that allow the production of more food with less resources.

**Acknowledgements**

Research funding and support from Newton Fund and EPSRC/RCUK (Grant Number: EP/P018165/1) are gratefully acknowledged.

Reference List

[1] C. S. Khor and G. Lalchand, "A review on sustainable power generation in Malaysia to 2030 : Historical perspective , current assessment , and future strategies," *Renew. Sustain. Energy Rev.*, vol. 29, pp. 952–960, 2014.

[2] M. Hurlbert, K. McNutt, and J. Rayner, "Policy Pathways: Transitioning to Sustainable Power Generation in Saskatchewan," *Renew. Energy L. Pol'y Rev.*, vol. 1, pp. 87–100, 2010.

[3] F. Fuso Nerini *et al.*, "Mapping synergies and trade-offs between energy and the Sustainable Development Goals," *Nat. Energy*, vol. 3, no. January, pp. 1–6, 2017.

[4] S. Ahmad and R. M. Tahar, “Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia,” *Renew. Energy*, vol. 63, pp. 458–466, 2014.

[5] S. Mekhilef, R. Saidur, A. Safari, and W. E. S. B. Mustaffa, “Biomass energy in Malaysia: Current state and prospects,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 7, pp. 3360–3370, 2011.

[6] N. Abdullah and F. Sulaiman, “The Oil Palm Wastes in Malaysia,” *Biomass Now - Sustain. Growth Use*, 2013.

[7] F. Sulaiman, N. Abdullah, H. Gerhauser, and a. Shariff, “An outlook of Malaysian energy, oil palm industry and its utilization of wastes as useful resources,” *Biomass and Bioenergy*, vol. 35, no. 9, pp. 3775–3786, 2011.

[8] S. Yusoff, “Renewable energy from palm oil – innovation on effective utilization of waste,” *J. Clean. Prod.*, vol. 14, no. 1, pp. 87–93, 2006.

[9] S. Sumathi, S. P. Chai, and A. R. Mohamed, “Utilization of oil palm as a source of renewable energy in Malaysia,” *Renew. Sustain. Energy Rev.*, vol. 12, no. 9, pp. 2404–2421, 2008.

[10] M. J. Chin, P. E. Poh, B. T. Tey, E. S. Chan, and K. L. Chin, “Biogas from palm oil mill effluent (POME): Opportunities and challenges from Malaysia’s perspective,” *Renew. Sustain. Energy Rev.*, vol. 26, pp. 717–726, 2013.

[11] KeTTHA, “National Renewable Energy Policy and Action Plan - Malaysia,” 2008.

[12] H. Hashim and W. S. Ho, “Renewable energy policies and initiatives for a sustainable energy future in Malaysia,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4780–4787, 2011.

[13] M. Ozturk *et al.*, “Biomass and bioenergy : An overview of the development potential in,” *Renew. Sustain. Energy Rev.*, vol. 79, no. April 2016, pp. 1285–1302, 2017.

[14] M. Balat and G. Ayar, “Biomass energy in the world, use of biomass and potential trends,” *Energy Sources*, vol. 27, no. 10, pp. 931–940, 2005.

[15] N. Sasaki *et al.*, “Woody biomass and bioenergy potentials in Southeast Asia between 1990 and 2020,” *Appl. Energy*, vol. 86, no. SUPPL. 1, pp. S140–S150, 2009.

[16] Malaysia Innovation Agency, “National Biomass Strategy 2020: New wealth creation for Malaysia’s palm oil industry,” 2013.

[17] A. H. Shamsuddin, “Development of renewable energy in Malaysia strategic initiatives for carbon reduction in the power generation sector,” in *Procedia Engineering*, 2012, vol. 49, pp. 384–391.

[18] F. Sulaiman *et al.*, “A Perspective of Oil Palm and Its Wastes,” *J. Phys. Sci.*, vol. 21, no. September 2016, pp. 67–77, 2010.

[19] T. K. Mun, “Best Practices & Success Stories of Biomass Industry in Malaysia,” *J. Sustain. Energy Environ.*, no. 2015, pp. 7–12, 2015.

[20] M. S. Alwani, H. P. S. A. Khalil, M. Asniza, S. S. Suhaily, A. S. N. Amiranajwa, and M. Jawaid, “Agricultural Biomass Raw Materials: The Current State and Future Potentialities,” in *Biomass and Bioenergy*, Springer, 2014, pp. 77–100.

[21] S. K. Loh, “The potential of the Malaysian oil palm biomass as a renewable energy source,” *Energy Convers. Manag.*, vol. 141, pp. 285–298, 2017.

[22] F.-Y. Ng, F.-K. Yew, Y. Basiron, and K. Sundram, “Journal of Oil Palm & The Environment An official publication of the Malaysian Palm Oil Council (MPOC) A Renewable Future Driven with Malaysian Palm Oil-based Green Technology,” *J. Oil Palm Environ.*, vol. 2, no. January, pp. 1–7, 2011.

[23] W. P. Q. Ng, H. L. Lam, F. Y. Ng, M. Kamal, and J. E. L. Heng, “Waste-to-wealth : green potential from palm biomass in Malaysia,” *J. Clean. Prod.*, vol. 34, no. September 2011, pp. 57–65, 2012.

[24] B. B. Nyakuma, “Biomass Energy Outlook in Malaysia using Functions of Innovation Systems,” 2018.

[25] S. M. Shafie, T. M. I. Mahlia, H. H. Masjuki, and A. Andriyana, “Current energy usage and sustainable energy in Malaysia : A review,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4370–4377, 2011.

[26] T. G. Chuah, a. G. K. Wan Azlina, Y. Robiah, and R. Omar, “Biomass as the Renewable Energy Sources in Malaysia: An Overview,” *Int. J. Green Energy*, vol. 3, no. 3, pp. 323–346, 2006.

[27] M. Z. Zailan, Yaakub, and S. H. and Jusoh, “In vitro Digestibility and Gas Production Characteristics of Four Napier ( Pennisetum purpureum ) Cultivars as Fresh Fodder,” vol. 19, no. December 2016, pp. 95–106, 2016.

[28] A. T. Negawo, A. Teshome, A. Kumar, J. Hanson, and C. S. Jones, “Opportunities for Napier Grass (Pennisetum purpureum) Improvement Using Molecular Genetics,” *Agronomy*, vol. 7, no. 2, p. 28, 2017.

[29] T. H. Boon, A. Raheem, W. A. W. A. K. Ghani, S. A. Hussain, and D. N. K. Sum, “Thermogravimetric Study of Napier Grass in Inert and Oxidative Atmospheres Conditions,” *J. Phys. Sci.*, vol. 28, p. 155, 2017.

[30] I. Y. Mohammed, Y. A. Abakr, F. K. Kazi, S. Yusup, I. Alshareef, and S. A. Chin,

"Comprehensive characterization of napier grass as a feedstock for thermochemical conversion," *Energies*, vol. 8, no. 5, pp. 3403–3417, 2015.

[31] U.S. department of energy, "Biomass Program Using Spatial Analysis to solve our Complex Bioenergy Challenges National Vision of a sustainable Future for Bioenergy achieving the Vision : Leveraging advanced gis," 2009.

[32] J. Wright *et al.*, "Water quality laboratories in Colombia: A GIS-based study of urban and rural accessibility," *Sci. Total Environ.*, vol. 485, pp. 643–652, 2014.

[33] J. Höhn, E. Lehtonen, S. Rasi, and J. Rintala, "A Geographical Information System (GIS) based methodology for determination of potential biomasses and sites for biogas plants in southern Finland," *Appl. Energy*, vol. 113, pp. 1–10, 2014.

[34] F. Zhang, D. M. Johnson, and J. W. Sutherland, "A GIS-based method for identifying the optimal location for a facility to convert forest biomass to biofuel," *Biomass and Bioenergy*, vol. 35, no. 9, pp. 3951–3961, 2011.

[35] R. J. Candare, M. Japitana, J. E. Cubillas, and C. B. Ramirez, "MAPPING OF HIGH VALUE CROPS THROUGH AN OBJECT-BASED SVM MODEL USING LIDAR DATA AND ORTHOPHOTO IN AGUSAN DEL NORTE PHILIPPINES.," *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 3, no. 7, 2016.

[36] H. M. Pagkalinawan *et al.*, "QUALITY ASSESSMENT AND CONTROL OF OUTPUTS OF A NATIONWIDE AGRICULTURAL LAND COVER MAPPING PROGRAM USING LIDAR: PHIL-LIDAR 2 PARMAP EXPERIENCE.," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 42, 2017.

[37] R. Zurita-Milla, E. Izquierdo-Verdiguier, and A. Rolf, "Identifying crops in smallholder farms using time series of WorldView-2 images," in *Analysis of Multitemporal Remote Sensing Images (MultiTemp), 2017 9th International Workshop on the*, 2017, pp. 1–3.

[38] I. L. Castillejo-González *et al.*, "Object-and pixel-based analysis for mapping crops and their agro-environmental associated measures using QuickBird imagery," *Comput. Electron. Agric.*, vol. 68, no. 2, pp. 207–215, 2009.

[39] C. Pohl, K. L. Chong, and J. van Genderen, "Multisensor Approach to Oil Palm Plantation Monitoring Using Data Fusion and GIS," in *36th Asian Conference on Remote Sensing 'Fostering Resiient Growth in Asia', Manila, Philippines*, 2015.

[40] C. Pohl, K. D. Kanniah, and C. K. Loong, "Monitoring oil palm plantations in Malaysia," in *Geoscience and Remote Sensing Symposium (IGARSS), 2016 IEEE International*, 2016, pp. 2556–2559.

[41] N. Kussul, M. Lavreniuk, A. Shelestov, and B. Yailymov, “Impact Of Different Satellite Data On The Crop Classification Map Accuracy In Ukraine,” 2017.

[42] K. L. Chong, K. D. Kanniah, C. Pohl, and K. P. Tan, “A review of remote sensing applications for oil palm studies,” *Geo-spatial Inf. Sci.*, vol. 20, no. 2, pp. 184–200, 2017.

[43] J. Miettinen, C. Shi, and S. C. Liew, “Towards automated 10–30 m resolution land cover mapping in insular South-East Asia,” *Geocarto Int.*, pp. 1–15, 2017.

[44] D. Lu, “The potential and challenge of remote sensing-based biomass estimation,” *Int. J. Remote Sens.*, vol. 27, no. 7, pp. 1297–1328, 2006.

[45] F. Frombo, R. Minciardi, M. Robba, and R. Sacile, “A decision support system for planning biomass-based energy production,” *Energy*, vol. 34, no. 3, pp. 362–369, 2009.

[46] Cheng, Y., Yu, L., Cracknell, A. P., & Gong, P. (2016). Oil palm mapping using Landsat and PALSAR: A case study in Malaysia. International journal of remote sensing, 37(22), 5431-5442.

[47] Deilmai, B. R., Ahmad, B. B., & Zabihi, H. (2014). Comparison of two classification methods (MLC and SVM) to extract land use and land cover in Johor Malaysia. In IOP Conference Series: Earth and Environmental Science (Vol. 20, No. 1, p. 012052). IOP Publishing.

[48] Rizeei, H. M., Shafri, H. Z., Mohamoud, M. A., Pradhan, B., & Kalantar, B. (2018). Oil palm counting and age estimation from WorldView-3 imagery and LiDAR data using an integrated OBIA height model and regression analysis. Journal of Sensors, 2018.

[49] Asraf, H. M., Nooritawati, M. T., & Rizam, M. S. (2012). A comparative study in kernel-based support vector machine of oil palm leaves nutrient disease. Procedia Engineering, 41, 1353-1359.

[50] Lee, J. S. H., Wich, S., Widayati, A., & Koh, L. P. (2016). Detecting industrial oil palm plantations on Landsat images with Google Earth Engine. Remote Sensing Applications: Society and Environment, 4, 219-224.

[51] Gutiérrez-Vélez, V. H., & DeFries, R. (2013). Annual multi-resolution detection of land cover conversion to oil palm in the Peruvian Amazon. Remote Sensing of Environment, 129, 154-167.

[52] Santoso, H., Tani, H., & Wang, X. (2017). Random Forest classification model of basal

stem rot disease caused by Ganoderma boninense in oil palm plantations. International journal of remote sensing, 38(16), 4683-4699.

[53] Tehrany, M. S., Pradhan, B., & Jebuv, M. N. (2014). A comparative assessment between object and pixel-based classification approaches for land use/land cover mapping using SPOT 5 imagery. Geocarto International, 29(4), 351-369.

[54] Shaharum, N. S. N., Shafri, H. Z. M., Ghani, W. A. W. A. K., Samsatli, S., Prince, H. M., Yusuf, B., & Hamud, A. M. (2019). Mapping the spatial distribution and changes of oil palm land cover using an open source cloud-based mapping platform. International Journal of Remote Sensing, 1-18.

[55] Xiong, J., Thenkabail, P., Tilton, J., Gumma, M., Teluguntla, P., Oliphant, A., ... & Gorelick, N. (2017). Nominal 30-m cropland extent map of continental Africa by integrating pixel-based and object-based algorithms using Sentinel-2 and Landsat-8 data on Google Earth Engine. Remote Sensing, 9(10), 1065.

[56] Miettinen, J., Shi, C., & Liew, S. C. (2016). 2015 Land cover map of Southeast Asia at 250 m spatial resolution. Remote sensing letters, 7(7), 701-710.

[57] Ramdani, F., & Hino, M. (2013). Land use changes and GHG emissions from tropical forest conversion by oil palm plantations in Riau Province, Indonesia. PloS one, 8(7), e70323.

[58] Forkuo, E. K., & Nketia, A. K. (2011). Digital soil mapping in GIS environment for crop-land suitability analysis. International journal of geomatics and geosciences, 2(1), 133.

[59] Paterson, R. R. M., Kumar, L., Taylor, S., & Lima, N. (2015). Future climate effects on suitability for growth of oil palms in Malaysia and Indonesia. Scientific reports, 5, 14457.

[60] Kumar, B., Kumar, S., Sinha, S., & Kumar, S. (2018). Utilization of acetone-butanol-ethanol-water mixture obtained from biomass fermentation as renewable feedstock for hydrogen production via steam reforming: Thermodynamic and energy analyses. *Bioresource Technology*, *261*, 385–393. https://doi.org/https://doi.org/10.1016/j.biortech.2018.04.035

[61] Kennes, D., Abubackar, H. N., Diaz, M., Veiga, M. C., & Kennes, C. (2016). Bioethanol production from biomass: carbohydrate vs syngas fermentation. *Journal of Chemical Technology & Biotechnology*, *91*(2), 304–317. https://doi.org/10.1002/jctb.4842

[62] Khor, W. C., Roume, H., Coma, M., Vervaeren, H., & Rabaey, K. (2016). Acetate accumulation enhances mixed culture fermentation of biomass to lactic acid. *Applied Microbiology and Biotechnology*, *100*(19), 8337–8348.

[63] Chng, L. M., Lee, K. T., & Chan, D. C. J. (2017). Evaluation on microalgae biomass for bioethanol production. In *IOP Conference Series: Materials Science and Engineering* (Vol. 206, p. 12018). IOP Publishing.

[64] Kuhad, R. C., Gupta, R., Khasa, Y. P., & Singh, A. (2010). Bioethanol production from Lantana camara (red sage): Pretreatment, saccharification and fermentation. *Bioresource Technology*, *101*(21), 8348–8354. https://doi.org/https://doi.org/10.1016/j.biortech.2010.06.043

[65] Amon, T., Amon, B., Kryvoruchko, V., Machmüller, A., Hopfner-Sixt, K., Bodiroza, V., … Zollitsch, W. (2007). Methane production through anaerobic digestion of various energy crops grown in sustainable crop rotations. *Bioresource Technology*, *98*(17), 3204–3212. https://doi.org/https://doi.org/10.1016/j.biortech.2006.07.007

[66] Triolo, J. M., Pedersen, L., Qu, H., & Sommer, S. G. (2012). Biochemical methane potential and anaerobic biodegradability of non-herbaceous and herbaceous phytomass in biogas production. *Bioresource Technology*, *125*, 226–232. https://doi.org/https://doi.org/10.1016/j.biortech.2012.08.079

[67] Sawatdeenarunat, C., Surendra, K. C., Takara, D., Oechsner, H., & Khanal, S. K. 2015). Anaerobic digestion of lignocellulosic biomass: Challenges and opportunities. *Bioresource Technology*, *178*, 178–186. https://doi.org/https://doi.org/10.1016/j.biortech.2014.09.103

[68] Wong, A. L., Chua, H., Lo, W. H., & Yu, P. H. F. (2000). Synthesis of bioplastics from food industry wastes with activated sludge biomass. *Water Science and Technology*, *41*(12), 55–59.

[69] Zahari, M. A. K. M., Ariffin, H., Mokhtar, M. N., Salihon, J., Shirai, Y., & Hassan, M. A. (2015). Case study for a palm biomass biorefinery utilizing renewable non-food sugars from oil palm frond for the production of poly(3-hydroxybutyrate) bioplastic. *Journal of Cleaner Production*, *87*, 284–290. https://doi.org/https://doi.org/10.1016/j.jclepro.2014.10.010

[70] Tang, S., Qin, C., Wang, H., Li, S., & Tian, S. (2011). Study on supercritical extraction of lipids and enrichment of DHA from oil-rich microalgae. *The Journal of Supercritical Fluids*, *57*(1), 44–49. https://doi.org/https://doi.org/10.1016/j.supflu.2011.01.010

[71] Halim, R., Gladman, B., Danquah, M. K., & Webley, P. A. (2011). Oil extraction from microalgae for biodiesel production. *Bioresource Technology*, *102*(1), 178–185. https://doi.org/https://doi.org/10.1016/j.biortech.2010.06.136

[72] Mardhiah, H. H., Ong, H. C., Masjuki, H. H., Lim, S., & Pang, Y. L. (2017). Investigation of carbon-based solid acid catalyst from Jatropha curcas biomass in biodiesel production. *Energy Conversion and Management*, *144*, 10–17. https://doi.org/https://doi.org/10.1016/j.enconman.2017.04.038

[73] Yellapu, S. K., Bezawada, J., Kaur, R., Kuttiraja, M., & Tyagi, R. D. (2016). Detergent assisted lipid extraction from wet yeast biomass for biodiesel: A response surface methodology approach. *Bioresource Technology*, *218*, 667–673. https://doi.org/https://doi.org/10.1016/j.biortech.2016.07.011

[74] Rambli, J., Azlina, W. A. K. G. W., Salleh, M. A. M., & Khezri, R. (2019). Evaluation of Biochar from Sago (Metroxylon Spp.) as a Potential Solid Fuel. *BioResources*,

*14*(1), 1928–1940.

[75] Mohammed, M., Salmiaton, A., Wan Azlina, W. a. K. G., Mohammad Amran, M. S., & Fakhru'l-Razi, A. (2011). Air gasification of empty fruit bunch for hydrogen-rich gas production in a fluidized-bed reactor. *Energy Conversion and Management*, *52*(2), 1555–1561. https://doi.org/10.1016/j.enconman.2010.10.023

[76] T. H. Oh, M. Hasanuzzaman, J. Selvaraj, S. C. Teo, and S. C. Chua, "Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth - An update," *Renew. Sustain. Energy Rev.*, no. May 2016, pp. 1–11, 2017.

[77] P. Yatim, M.-N. Mamat, S. H. Mohamad-Zailani, and S. Ramlee, "Energy policy shifts towards sustainable energy future for Malaysia," *Clean Technol. Environ. Policy*, 2016.

[78] Yatim, P. et al. (2017) 'Overview of the key risks in the pioneering stage of the Malaysian biomass industry', *Clean Technologies and Environmental Policy*. Springer Berlin Heidelberg, 19(7), pp. 1825–1839. doi: 10.1007/s10098-017-1369-2

[79] Agh amohammadi, N. *et al.* (2016) 'An Investigation of Sustainable Power Generation from Oil Palm Biomass: A Case Study in Sarawak', *Sustainability*. Multidisciplinary Digital Publishing Institute, 8(5), p. 416. doi: 10.3390/su8050416.

[80] KeTTHA (2008) *National Renewable Energy Policy and Action Plan - Malaysia*, *National Renewable Energy Policy*.

[81] KeTTHA (2017) *Green Technology Master Plan Malaysia 2017 - 2030*.

[82] Yatim, P., Ngan, S. L. and Lam, H. L. (2017) 'Financing Green Growth in Malaysia : Enabling Conditions and Challenges', *Chemical Engineering Transactions*, 61, pp. 1579–1584. doi: 10.3303/CET1761261.

[83] Md Jaye, I. F. (2019) *Renewable , Local Electricity Generation from Palm Oil Mill Residues : A Case Study from Peninsular Malaysia*. University of Surrey,United Kingdom. Available at: http://epubs.surrey.ac.uk/850425/1/Ida Fahani Md Jaye - Renewable%2C Local Electricity Generation from Palm Oil Mill Residues A Case Study from Peninsular Malaysia.pdf.

[84] Abdul Rahim, K. (2014) 'Towards Low Carbon Economy via Carbon Intensity Reduction in Malaysia', *Journal of Economics and Sustainable Development*, 5(16), pp. 123–133.

[85] Petinrin, J. O. and Shaaban, M. (2015) 'Renewable energy for continuous energy sustainability in Malaysia', *Renewable and Sustainable Energy Reviews*. Elsevier, 50, pp. 967–981. doi: 10.1016/j.rser.2015.04.146.

[86] Shirley, R. and Kammen, D. (2015) 'Energy planning and development in Malaysian Borneo: Assessing the benefits of distributed technologies versus large scale energy mega-projects', *Energy Strategy Reviews*, 8, pp. 15–29. doi: 10.1016/j.esr.2015.07.001.

[87] Ali R., Daut, I. and Taib, S. (2012) 'A review on existing and future energy sources for electrical power generation in Malaysia', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 16(6), pp. 4047–4055. doi: 10.1016/j.rser.2012.03.003.

[88] Bazmi, . A., Zahedi, G. and Hashim, H. (2015) 'Design of decentralized biopower generation and distribution system for developing countries', *Journal of Cleaner Production*. Elsevier Ltd, 86(January), pp. 209–220. doi: 10.1016/j.jclepro.2014.08.084.

[89] Chin, M. J. *et al.* (2013) 'Biogas from palm oil mill effluent (POME): Opportunities and challenges from Malaysia's perspective', *Renewable and Sustainable Energy Reviews*, 26, pp. 717–726. doi: 10.1016/j.rser.2013.06.008.

[90] Wan, Wan, Y. K., Sadhukhan, J. and Ng, D. K. S. (2015) 'Techno-Economic Evaluation of Integrated Bioethanol Plant for Sago Starch Processing Facility', *Chemical Engineering Research and Design*. Institution of Chemical Engineers. doi: 10.1016/j.cherd.2015.09.017.

[91] Wu, Q. *et al.* (2017) 'Sustainable and renewable energy from biomass wastes in palm oil industry: A case study in Malaysia', *International Journal of Hydrogen Energy*. Elsevier Ltd, 42(37), pp. 23871–23877. doi: 10.1016/j.ijhydene.2017.03.147.

[92] Energy Commission (2017) Peninsular Malaysia Electricity Supply Outlook 2017. Available at: http://www.st.gov.my/index.php/en/all-publications/item/765-peninsular-malaysia-electricity-supplyindustry-outlook-2017

[93] Kazi, F. K. *et al.* (2010) 'Techno-economic comparison of process technologies for biochemical ethanol production from corn stover', *Fuel*. Elsevier Ltd, 89(SUPPL. 1), pp. S20–S28. doi: 10.1016/j.fuel.2010.01.001.

[94] Abdul Malek, A. B. . *et al.* (2017) 'Techno-economic analysis and environmental impact assessment of a 10 MW biomass-based power plant in Malaysia', *Journal of Cleaner Production*. Elsevier Ltd, 141, pp. 502–513. doi: 10.1016/j.jclepro.2016.09.057.

[95] Lauven, L. P., Liu, B. and Geldermann, J. (2013) 'Investigation of the influence of plant capacity on the economic and ecological performance of cassava-based bioethanol', *Chemical Engineering Transactions*, 35, pp. 595–600. doi: 10.3303/CET1335099.

[96] Reeb, C. W. *et al.* (2014) 'Supply Chain Analysis, Delivered Cost, and Life Cycle Assessment of Oil Palm Empty Fruit Bunch Biomass for Green Chemical Production in Malaysia', *Bioresources*, 9(3), pp. 5385–5416. doi: 10.15376/biores.9.3.5385-5416.

[97] Ong, C. L. *et al.* (2016) 'Designing model for biomass transport cost of biofuel refinery in Malaysia', in *Proceeding of the Burapha University International Conferences 2016*, pp. 610–621. Available at: www.buuconference.buu.ac.th.

[98] Leboreiro, J. and Hilaly, A. K. (2013) 'Analysis of supply chain, scale factor, and optimum plant capacity for the production of ethanol from corn stover', *Biomass and Bioenergy*. Elsevier Ltd, 54, pp. 158–169. doi: 10.1016/j.biombioe.2013.03.021.

[99] Mustapa, S. I., Leong, Y. P. and Hashim, A. H. (2010) 'Issues and challenges of renewable energy development: A Malaysian experience', in *Proceedings of the International Conference on Energy and Sustainable Development: Issues and Strategies (ESD 2010)*, pp. 1–6. doi: 10.1109/ESD.2010.5598779.

[100] R. Kardooni, S. Yusoff, and F. Kari, "Renewable energy technology acceptance in Peninsular Malaysia," *Energy Policy*, vol. 88, pp. 1–10, 2016.

[101] Maulud, A. L. and Saidi, H. (2012) ‘The Malaysian Fifth Fuel Policy: Re-strategising the Malaysian Renewable Energy Initiatives’, *Energy Policy*. Elsevier, 48, pp. 88–92. doi: 10.1016/j.enpol.2012.06.023.

[102] Sen, S. and Ganguly, S. (2017) ‘Opportunities, barriers and issues with renewable energy development – A discussion’, *Renewable and Sustainable Energy Reviews*, pp. 1170–1181. doi: 10.1016/j.rser.2016.09.137.

[103] Gheewala SH, Berndes G, Jewitt G. The bioenergy and water nexus. Biofuels, Bioprod Biorefining 2011;5:353–60.

[104] Yang H, Zhou Y, Liu J. Land and water requirements of biofuel and implications for food supply and the environment in China. Energy Policy 2009;37:1876–85.

[105] Rulli MC, Bellomi D, Cazzoli A, De Carolis G, D’Odorico P. The water-land-food nexus of first-generation biofuels. Sci Rep 2016;6:22521.

[106] Martinez-Hernandez E, Samsatli S. Biorefineries and the food, energy, water nexus—towards a whole systems approach to design and planning. Curr Opin Chem Eng 2017;18:16–22.

[107] Taniguchi M, Endo A, Gurdak JJ, Swarzenski P. Water-energy-food nexus in the Asia-Pacific region 2017.

[108] Endo A, Tsurita I, Burnett K, Orencio PM. A review of the current state of research on the water, energy, and food nexus. J Hydrol Reg Stud 2017;11:20–30.

[109] Rasul G. Food, water, and energy security in South Asia: a nexus perspective from the Hindu Kush Himalayan region☆. Environ Sci Policy 2014;39:35–48.

[110] Smajgl A, Ward J. The water-food-energy nexus in the Mekong region 2013.

[111] Karabulut AA, Crenna E, Sala S, Udias A. A proposal for integration of the ecosystem-water-food-land-energy (EWFLE) nexus concept into life cycle assessment: A synthesis matrix system for food security. J Clean Prod 2018;172:3874–89.

[112] Albrecht TR, Crootof A, Scott CA. The Water-Energy-Food Nexus: A systematic review of methods for nexus assessment. Environ Res Lett 2018;13:43002.

[113] Veldhuis AJ, Yang A. Integrated approaches to the optimisation of regional and local food–energy–water systems. Curr Opin Chem Eng 2017;18:38–44.

[114] Bieber N, Ker JH, Wang X, Triantafyllidis C, van Dam KH, Koppelaar RHEM, et al. Sustainable planning of the energy-water-food nexus using decision making tools. Energy Policy 2018;113:584–607.

[115] Hang MYLP, Martinez-Hernandez E, Leach M, Yang A. Designing integrated local production systems: a study on the food-energy-water nexus. J Clean Prod 2016;135:1065–84.

[116] Karan E, Asadi S, Mohtar R, Baawain M. Towards the optimization of sustainable food-

energy-water systems: A stochastic approach. J Clean Prod 2018;171:662–74.

[117] Ahmed F, Siwar C, Begum RA. Water resources in Malaysia: Issues and challenges. J Food, Agric Environ 2014;12:1100–4.

[118] Tidwell V, Moreland B. Mapping water consumption for energy production around the Pacific Rim. Environ Res Lett 2016;11:94008.

[119] Ismail N, Mohamed Yusuff MK. The modernized and higher technology agriculture of Malaysia: development of livestock industry, International Conference on Malaysia in Global Perspective, 27-28, Cairo University, Egypt. September 2009.

[120] Dardak RA. Transformation of agricultural sector in Malaysia through agricultural policy. Malaysian Agric Res Dev Inst (MARDI), Malaysia 2015;7.

[121] Djojodihardjo, H. and Ahmad, A. D. (2016) ‘Opportunities and Challenges for Climate-Smart Agriculture’, *Advances in Energy and Environmental Science and Engineering*, pp. 166–177. Available at: http://www.wseas.us/e-library/conferences/2015/Michigan/LENFI/LENFI-23.pdf.

[122] I. Mat, M. R. Mohd Kassim, A. N. Harun and I. M. Yusoff, "Smart Agriculture Using Internet of Things," *2018 IEEE Conference on Open Systems (ICOS)*, Langkawi Island, Malaysia, 2018, pp 54-59. doi:10.1109/ICOS.2018.8632817

[123] N. H. N. Ibrahim, A. R. brahim, I. Mat, A. N. Harun and G. Witjaksono, "IR 4.0 using IoT and LORAWAN to Accelerate Lentinula Edodes Growth," *2018 2nd International Conference on Smart Sensors and Application (ICSSA)*, Kuching, 2018, pp. 28-32. doi:10.1109/ICSSA.2018.8535954

[124] M. R. M. Kassim and A. N. Harun, "Wireless sensor networks and cloud computing integrated architecture for agricultural environment applications," *2017 Eleventh International Conference on Sensing Technology (ICST)*, Sydney, NSW, 2017, pp. 1-5. doi:10.1109/ICSensT.2017.8304445

[125] M. A. Romli, S. Daud, S. M. Zainol, P. L. E. Kan and Z. A. Ahmad, "Automatic RAS data acquisition and processing system using fog computing," *2017 IEEE 13th Malaysia International Conference on Communications (MICC)*, Johor Bahru, 2017, pp. 229-234.doi: 10.1109/MICC.2017.8311764

[126] A. I. Zainal Abidin, F. A. Fadzil and Y. S. Peh, "Micro-controller Based Fertilizer Dispenser Control System," *2018 IEEE Conference on Wireless Sensors (ICWiSe)*, Langkawi, Malaysia, 2018, pp. 17-22.doi: 10.1109/ICWISE.2018.8633277

[127] P. Srinivasulu, M. S. Babu, R. Venkat and K. Rajesh, "Cloud service oriented architecture (CSoA) for agriculture through internet of things (IoT) and big data," *2017 IEEE International Conference on Electrical, Instrumentation and Communication Engineering (ICEICE)*, Karur, 2017, pp. 1-6. doi: 10.1109/ICEICE.2017.8191906

[128] A. H. Fauzi, D. N. F. Awang Iskandar and M. A. A. Suhaimi, "Automated machine for sorting Sarawak pepper berries," *2015 9th International Conference on IT in Asia (CITA)*,pp.1-4.doi:10.1109/CITA.2015.7349840

[129] K. Kipli *et al.*, "Image Processing Mobile Application For Banana Ripeness Evaluation," *2018 International Conference on Computational Approach in Smart Systems Design and Applications (ICASSDA)*, Kuching, 2018, pp. 1-5. doi:10.1109/ICASSDA.2018.8477600

[130] Norasma, C. Y. N. *et al.* (2019) 'Unmanned Aerial Vehicle Applications in Agriculture', *IOP Conference Series: Materials Science and Engineering*, 506(1). doi: 10.1088/1757-899X/506/1/012063.

[131] Shamshiri, R. R. *et al.* (2018) 'Fundamental Research on Unmanned Aerial Vehecles to Support Precision Agriculture in Oil Palm Plantation', in *Agricultural Robots - Fundamentals and Application*, pp. 91–116. doi: http://dx.doi.org/10.5772/intechopen.80936.

[132] Mahsuri, I. *et al.* (2018) 'Determination of rubber-tree clones leaf diseases spectral using Unmanned Aerial Vehicle compact sensor', *IOP Conference Series: Earth and Environmental Science*, 169, p. 012059. doi: 10.1088/1755-1315/169/1/012059.

[133] Hashim, N. M. Z. *et al.* (2015) 'Agriculture Monitoring System: A Study', *Jurnal Teknologi*, 77(1), pp. 53–59. doi: 10.11113/jt.v77.4099.

[134] Said, H. B., Nordin, R. and Abdullah, N. F. (2019) 'Energy Models of Zigbee-Based Wireless Sensor Networks for Smart-Farm', *Jurnal Kejuturetaan*, 31(1), pp. 77–83. doi: 10.17576/jkukm-2019-31(1)-09.

[135] Abdullah, F. A. and Samah, B. A. (2013) 'Factors impinging farmers' use of agriculture technology', *Asian Social Science*, 9(3), pp. 120–124. doi: 10.5539/ass.v9n3p120.

[136] Umar, M. S., Jennings, P. and Urmee, T. (2014) 'Sustainable electricity generation from oil palm biomass wastes in Malaysia: An industry survey', *Energy*. Elsevier Ltd, 67, pp. 496–505. doi: 10.1016/j.energy.2014.01.067.